ELEMENTS OF COLOR
IN PROFESSIONAL MOTION PICTURES

The Society of Motion Picture and Television Engineers

G. Elliott Colburn

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ELEMENTS OF COLOR IN PROFESSIONAL MOTION PICTURES

PREPARED BY A SPECIAL COMMITTEE OF THE

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

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CONTENTS

Foreword 6

1. Introduction 7
2. Color Fundamentals 8
3. Characteristics of Color 17
4. Color Films and Processes 25
5. Planning a Motion Picture in Color 38
6. Photographing a Motion Picture in Color 51
7. Color Photography Outdoors 58
8. Color Photography in the Studio 69
9. Special Effects 80
10. Color Processing and Printing 84
11. Motion Pictures and Color Television 91
12. Visual Effects 95

Committee Members and Their Affiliations 104

Cover from C. B. De Mille's *The Ten Commandments*
(Courtesy Paramount Pictures Corp.)

FOREWORD

About two years ago the suggestion was made that the Color Committee of the Society of Motion Picture and Television Engineers could perform a real service by preparing a basic treatise on color and color photography especially for the non-engineering people who have such an important role in the making of color motion pictures. These are the studio artists and craftsmen who collaborate in applying the images to the film, and therefore share the responsibility for good color with the technically trained personnel who make, process and print the film. The suggestion was the result of a growing feeling that the contribution of the studio group to color photography would be greater if talent and artistic experience were supplemented by an understanding of the basic scientific principles of color. Accordingly, a proposal was made to the Color Committee that a treatise be prepared that might serve to bridge the gap between the artistic approach and scientific know-how.

This proposal was received with enthusiasm by the members of the Color Committee. Wilton R. Holm was drafted to organize a special committee to carry out this project. Members of his group were chosen from the top authorities of the industry. Thus the information on each specialized subject was supplied by an acknowledged leader in the field. Indeed, many subjects had more than one contributor so that different points of view were represented in controversial matters.

In the interest of consistency of style and emphasis, the various contributions have been recast where necessary. This considerable task fell to the lot of the Chairman, "Bill" Holm. Valuable assistance in reviewing the manuscript was supplied by Herbert E. Behrens, Vernon W. Blanchard, William F. Kelley, Walter I. Kisner, Wadsworth E. Pohl and Lloyd Thompson. For a final review of the completed manuscript we are indebted to Walter I. Kisner.

Appreciation is due all the members of the Committee who contributed their sections generously and enthusiastically. Particular credit is merited by Chairman Holm, who was the sparkplug of the entire activity and carried by far the heaviest load of the work. He was able to bring it rapidly to completion despite heavy pressures from other obligations.

We believe that this report will contribute much to the industry by bringing about a broader understanding of the problems, capabilities and limitations of color reproduction, and the materials of color photography.

J. P. Weiss
Chairman of the SMPTE Color Committee

1. Introduction

An increasingly greater amount of motion-picture production is being photographed in color. This is true not only for theatrical and television films, but for industrial and educational films as well.

Color is a tremendously complex subject, embracing both art and science, and the production of motion pictures in color requires the efforts of many people possessing various skills, specific training, imagination and exactitude. As in other fields of endeavor, specialization is the guiding principle, and few of the artists and craftsmen who work in motion pictures have much knowledge of problems posed by color in departments other than their own. The Society of Motion Picture and Television Engineers believes, therefore, that a publication devoted to a broad discussion of the use of color in professional motion pictures should be of value to the industry. It is toward that goal that this work is directed.

There is no thought to offer this publication as a substitute for the training and experience required to achieve excellence in any of the arts and crafts of motion-picture making. Rather, it is offered in the hope that it may provide an insight into the fundamental problems associated with the use of color in various departments, enabling, perhaps, some of the motion-picture artists and craftsmen to perform their own functions more efficiently, and to integrate them better into the cooperative effort of making color motion pictures.

Of necessity, many of the more technical aspects of color have been simplified here. Many of those who read this book may subsequently desire a more comprehensive treatment of the subject of color. For them, a text such as *An Introduction to Color,* by Ralph M. Evans (John Wiley & Sons, 1948), may be useful.

This Committee wishes to express its appreciation to E. I. du Pont de Nemours & Company, the Eastman Kodak Company, Metro-Goldwyn-Mayer Pictures, The Paramount Pictures Corporation, and the Technicolor Corporation for the color illustrations contained in this report. Special appreciation is extended to the Eastman Kodak Company for supplying many of the color printing plates. Finally, the Chairman wishes to express his appreciation to the members of this Committee for their enthusiastic support and contributions.

WILTON R. HOLM
Committee Chairman

2. Color Fundamentals

In order to discuss the various aspects of color which are important in the production of color motion pictures, we should first make sure we have a definite idea of what is meant by "color." And since color depends first of all upon light, it is well for us to begin by examining the nature of light itself.

NATURE OF LIGHT

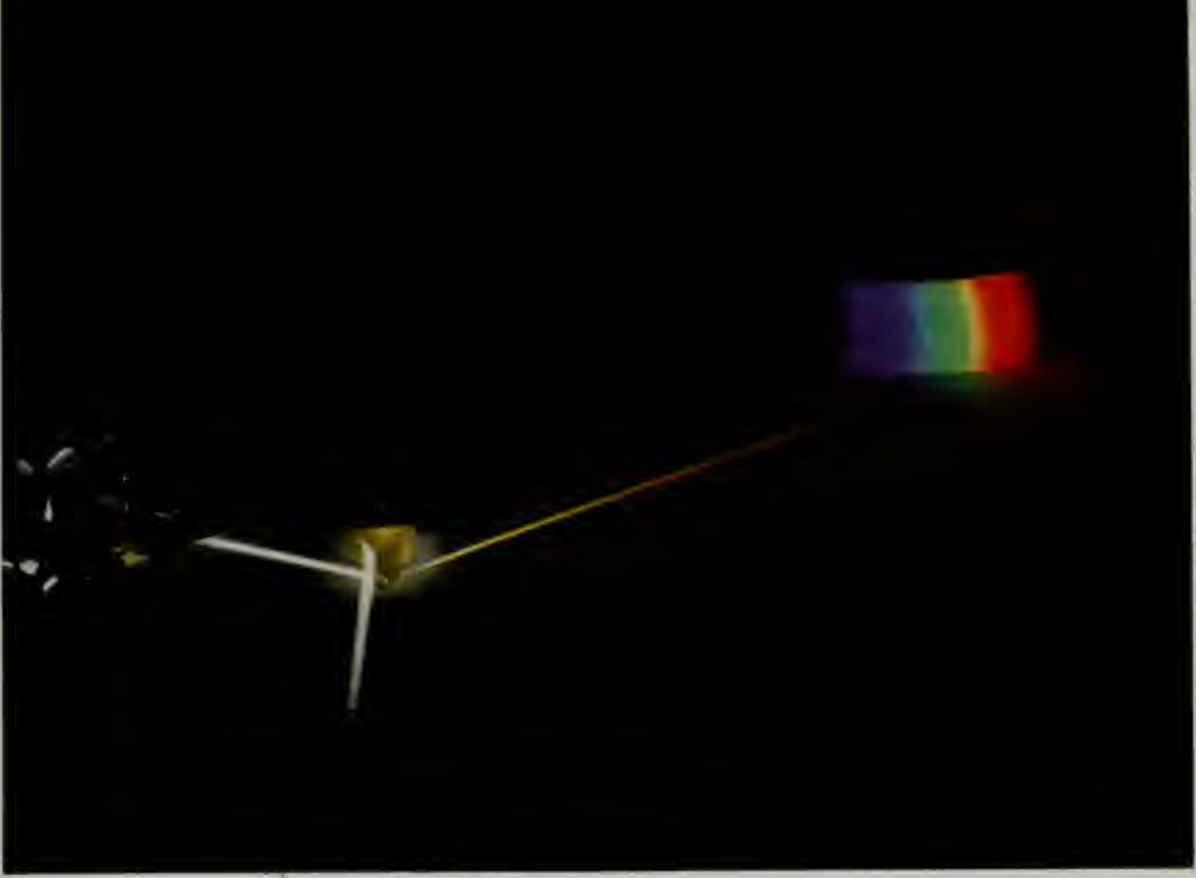
Light is one of a number of known forms of radiant energy. Other forms of radiant energy with which we are familiar are radio and television waves, infrared (heat) radiation, ultraviolet radiation (that which produces sunburn), and x-rays. All of these forms of radiation travel with wave motion, and they travel through the air (or through space from the sun, moon or stars) at the incredible speed of 186,000 miles per *second* — almost seven hundred million miles per hour! They differ, however, in wavelength. Radio waves, for example, are of very long wavelengths, in some instances measuring several miles from the crest of one wave to the crest of the next. On the other hand, some forms of radiant energy have wavelengths which are almost infinitesimally small. Gamma rays, for instance, which are given off by some radioactive materials, have wavelengths which measure less than a billionth of an inch.

The various forms of radiant energy, in order of increasing wavelengths, may be listed as follows:

Gamma Rays
X-rays
Ultraviolet Radiation
Light
Infrared Radiation
Radio Waves

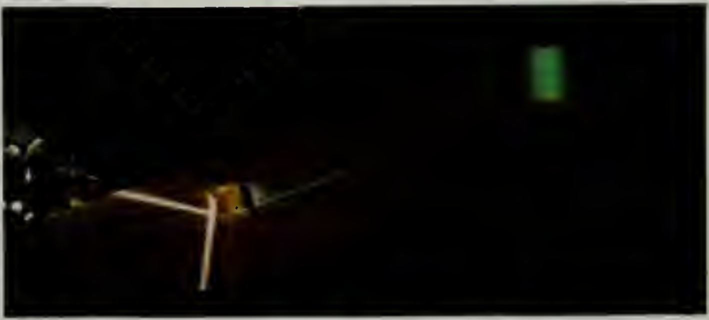
As intimated above, each of these forms of radiant energy is composed of a series of wavelengths covering a more or less definite range. Consider, for example, that region of wavelengths known as *Radio Waves.* There are some radio waves, as we have said, which measure miles in wavelength. The standard (AM) broadcast band of radio waves has wavelengths which vary from about 600 feet at one end (frequency of 1600 kilocycles) to about 2000 feet at the other (frequency of 550 kilocycles). FM radio and television waves are much shorter, having an average wavelength of about 10 feet. Radar waves are shorter still, some having a wavelength of less than 1 inch. Yet all of these various waves, and many more, belong to that region of wavelengths which we define as *Radio Waves.*

As a matter of fact, the various forms or regions of wavelengths, taken together in the order listed, constitute a continuous series of wavelengths, each of which differs from its neighbors by only an infinitesimal amount. This is true not only for the wavelengths *within* any given region, but also for those *between* any two regions. For example, not only does one gamma ray differ from the next longer or the next shorter gamma ray by an infinitesimal amount, but the longest gamma



The prism bends light of the shorter wavelengths more than light of the longer wavelengths, thus spreading a narrow beam of white light out into the visible spectrum. (The beam extending toward the bottom of the picture is reflected from the surface of the prism without entering it.)

A red filter between prism and screen allows only light of the longer wavelengths to pass.



A green filter passes only the center part of the spectrum, absorbing blue and red light.

A blue filter passes only light of the shorter wavelengths, absorbing green and red light.

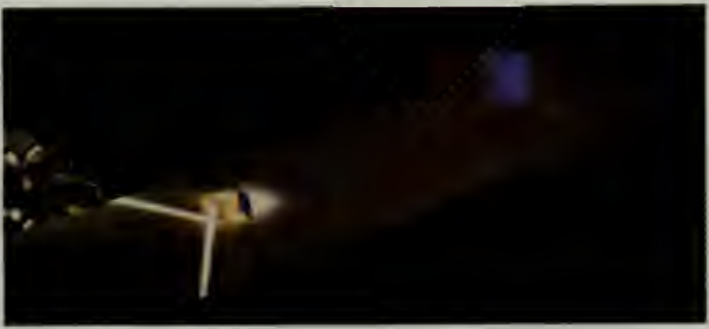


FIGURE 1 (Courtesy Eastman Kodak Company)

ray also differs from the shortest x-ray by only an infinitesimal amount. Likewise, the longest x-ray differs from the shortest ultraviolet ray by only an infinitesimal amount. And so on throughout the various wavelength regions. Thus this entire series of wavelengths, from the shortest gamma ray to the longest radio wave, comprises a smooth gradation of wavelengths which gradually become longer and longer, in somewhat the same manner as the musical tones on a piano become gradually lower and lower if one starts at the highest note on the keyboard and progresses to the lowest, striking each key in succession. This whole tremendous series of radiant energy wavelengths is known as the *electromagnetic spectrum.*

Because some of the wavelengths of the electromagnetic spectrum are so extremely short, it has been necessary to adopt special units of measurement to describe them. Just as the distance around a girl's waist is measured in inches rather than in fractions of a mile, so the wavelengths of light are measured in *millimicrons* instead of fractions of an inch. A millimicron is simply one twenty-five millionth of an inch.

Light — those wavelengths to which the human eye is sensitive — embraces only an extremely narrow band of wavelengths near the center of the electromagnetic spectrum. The shortest wavelength to which the eye will respond is about 400 millimicrons (about 16 millionths of an inch), while the longest is about 700 millimicrons (about 28 millionths of an inch). This very narrow band of wavelengths which we call "light" is also known, logically enough, as the *visible spectrum.* And even though the difference in wavelength from one end to the other of this visible spectrum is only about 12 millionths of an inch, this very narrow band of wavelengths is nevertheless responsible for all the sensations which human vision can produce.

A scientific definition of light is — *The aspect of radiant energy of which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye.* This definition is not really as imposing as it appears at first sight, and from it we can draw some rather important conclusions.

We know that the eye contains a lens which forms an image on the rear surface of the eyeball. This rear surface we call the *retina.* It consists of many tiny sensitive elements — about seven million in each eye. Each of these sensitive elements, like a tiny phototube, causes an electrical disturbance whenever light falls upon it. These light-sensitive elements of the retina are connected to nerve fibers, which are collected just behind each eyeball into a single cable called the *optic nerve.* This optic nerve runs from each eyeball back to the base of the brain. Thus the process of seeing is initiated by radiant energy — light — entering the eye, being imaged onto the retina, stimulating the sensitive elements there to cause an electric current to flow along the optic nerves to the brain.

We see then that radiant energy is actually the initiator of the process of seeing, yet radiant energy is purely *physical* — that is, it exists independently of the human observer. In the wavelength region to which the eye is sensitive, radiant energy provides a stimulus which causes a *visual sensation* and results in *visual perception.* Sensation and perception are associated with mental processes, however, and are therefore *psychological* expressions. Our definition of light, then, since it includes both physical and psychological factors, is actually expressed in *psycho-physical* terms — that is, terms which interrelate both physical and mental processes. A good example of this interrelation may be seen in connection with white light.

WHITE LIGHT

When all wavelengths between 400 and 700 millimicrons are presented to the eye in approximately equal quantities, we get the sensation of colorless or "white" light. We say approximately equal quantities, for there is no absolute standard for white. This is because a human observer, within limits, is able to adapt his mental and visual processes to changing conditions. Thus the absolute quantities of the various wavelengths between 400 and 700 millimicrons can be varied somewhat, and the resulting mixture will still appear white to an observer.

For example, at night (or during the day in a place where there is no daylight) our eyes will accept the light from an ordinary tungsten electric light bulb as white. It appears white to us even though, for the same visual intensity, it contains substantially more red and less blue than does daylight. In a room illuminated by daylight, however, a tungsten lamp appears distinctly yellowish because our eyes are now adapted to daylight. For the same reason moonlight appears to have a definite bluish cast to most people, because they usually step out into the moonlight from lamplighted rooms. They therefore see the moonlight with eyes adapted to the more yellowish tungsten illumination.

THE SPECTRUM

Under suitable conditions we can separate white light into its constituent wavelengths. This is done on a majestic scale in nature when sunlight, falling on the curved surfaces of raindrops, is dispersed into the familiar rainbow.

This same visible spectrum, containing all the wavelengths from 400 to 700 millimicrons, can also be produced in a dark room by passing a narrow beam of white light through a glass prism, as shown in the large illustration of Fig. 1. Here the resulting spectrum is seen falling on a white screen, from which it is reflected to our eyes. The principal colors we can distinguish in the printed reproduction are blue, blue-green, green, yellow and red. In viewing an actual spectrum, however, we would be much more aware of its continuous nature; we would see that the color shifts gradually as the wavelength of light changes, and that we can detect many more different colors in the spectrum itself than in the reproduction. The colors of an actual spectrum are the purest colors possible, because each is seen in isolation, unaffected by mixture with light of other wavelengths.

FILTERS

As a prelude to understanding how the human eye sees color, let us consider briefly the action of light filters, shown in the three small illustrations of Fig. 1.

If we place a red filter in the path of the light traveling from the prism to the screen, we find that all the colors of the spectrum but the red region are missing. The red filter has absorbed all the visible wavelengths except those giving rise to a sensation of redness. Here, then, is the reason the red filter looks red — it transmits only the predominantly red region of the spectrum, those wavelengths between 600 and 700 millimicrons. Likewise, a green filter transmits only the predominantly green region of the spectrum, between 500 and 600 millimicrons. And a blue filter transmits only the predominantly blue region of the spectrum, between 400 and 500 millimicrons.

COLOR VISION AND THE PRIMARY COLORS

To simplify the principles of color vision, we may compare the eye to a radio. Both are sensitive to certain bands of wavelengths. A radio is selective in its reception; it can be tuned to receive one wavelength only, rejecting all others, even though several signals of various wavelengths from other stations may be present at the antenna at the same time.

In contrast to a radio, however, the eye has no tuning mechanism. It responds simultaneously to all visible wavelengths which enter it, and light of one particular wavelength cannot be distinguished by the eye unless that wavelength is received alone. For example, the eye readily identifies a certain green when that green is seen in the spread-out spectrum, but it is unable to isolate a green sensation from white light in which that green is present.

Since the eye interprets all the light that enters it without being able to analyze the various mixtures of wavelengths the way the ear, for example, can determine the constituent tones of a chord, we may logically conclude that the eye does not have a separate sensitivity mechanism for each separate wavelength of the visible spectrum. How then, does the eye see colors? The answer to this question can be furnished by a practical experiment with our red, green and blue filters, for with them we can demonstrate that practically all colors can be matched by mixtures of various quantities of red, green and blue light. The eye behaves, therefore, as though it had three receptor mechanisms, one sensitive to red light, one sensitive to green light, and one sensitive to blue light. Thus the eye sees all colors as mixtures of red, green and blue. These colors are known as the *primary colors.*

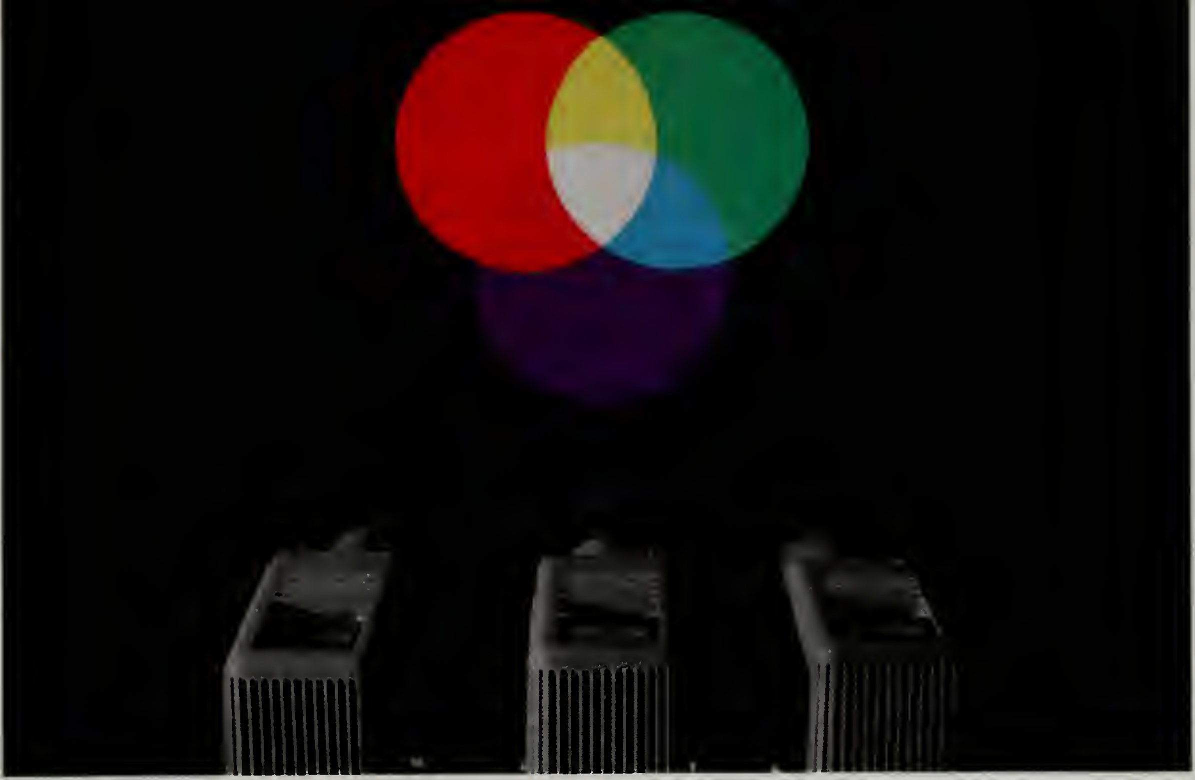
There may be a point of confusion here to some readers who learned as long ago as their first set of water color paints that the primary colors are red, blue and yellow. Confusion on this point may largely be avoided if we keep in mind that we are discussing mixtures of light, not mixtures of pigments or paints. The difference will be explained shortly.

ADDITIVE COLOR MIXTURE

Let us consider three partially overlapping beams of light of approximately equal intensity from three projectors, one of which is filtered red, the second filtered green and the third filtered blue, as shown in the large illustration at the top of Fig. 2. Here we can see at a glance how adding mixtures of these primary colors will produce other colors.

Where all three beams overlap, we get white. Where the red beam overlaps the blue we get a purple hue, known as *magenta.* Where the green beam overlaps the blue we get a blue-green hue known as *cyan.* And where the green beam overlaps the red we get a red-green hue which we know as *yellow.* It is interesting to note that in both the cyan (blue-green) and the magenta (blue-red) we feel that we can trace the contributions made by the parent colors. The cyan looks blue-green, and the magenta looks blue-red. In the yellow, however, this is not the case. A mixture of red and green light gives the sensation of yellow, and both parent colors have completely lost their identity. Yellow does not look red-green.

Other colors can be produced by mixtures of red, green and blue light simply by varying the relative strength of the primaries. A bluer magenta, for example, may be produced by using a brighter blue beam and a weaker red beam. Conversely, a redder magenta may be produced by having the red

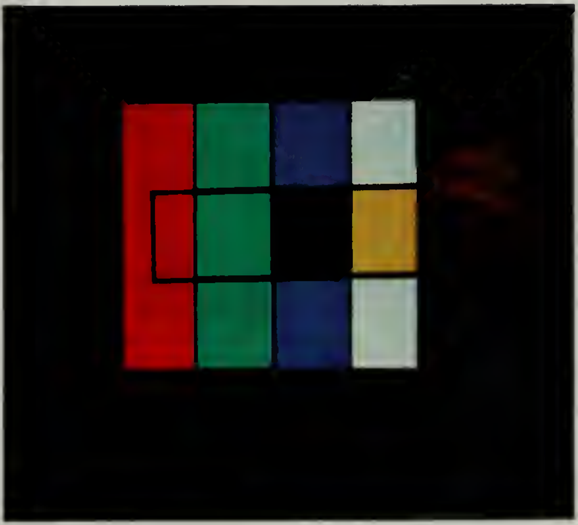


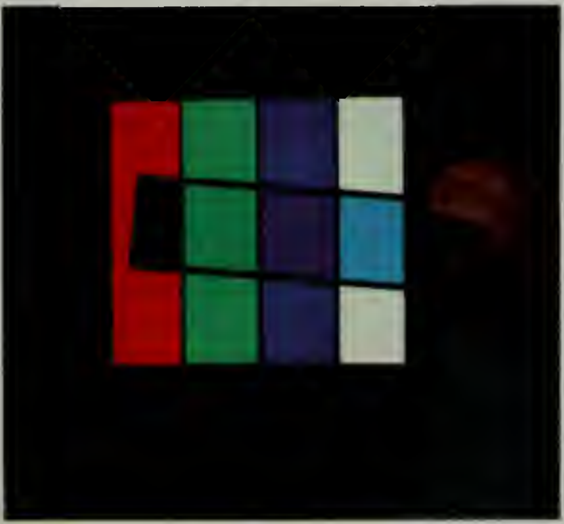
Additive mixture of the colored light from projectors covered by red, green and blue filters. Combined in pairs, the beams give cyan, magenta and yellow. Where all three beams overlap, all three of the visual receptor systems are stimulated, and the screen appears white.

A yellow filter absorbs blue light, transmitting green and red light.

A magenta filter absorbs green light, transmitting blue and red light.

A cyan filter absorbs red light, transmitting blue and green light.





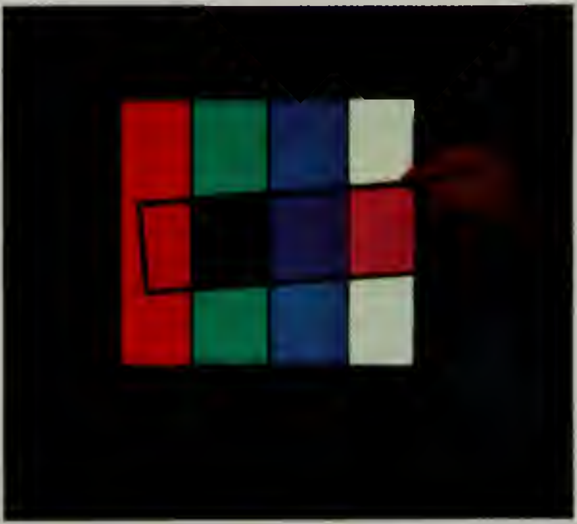


FIGURE 2 (Courtesy Eastman Kodak Company)

beam brighter than the blue. And so on, using beams of various intensities of any two of the primaries. Since matching a wide range of colors in this way involves addition of colored lights, the red, green and blue primaries are often further specified as the *additive primaries.*

In color photography, the three colors produced by equal mixtures of any two of the additive primaries — that is, the colors magenta, cyan and yellow — are of particular importance. Since magenta, cyan and yellow each results from a mixture of two of the three additive primaries, then magenta, cyan and yellow each represents white light minus one of the additive primaries. Magenta, cyan and yellow are thus the *complementary* colors of the three additive primaries green, red and blue, respectively. (Two colors of light are said to be complementary if, when added together in equal amounts, they produce white.)

Thus, cyan, for example, is complementary to red. Or, in other words, cyan light and red light added together produce white light. Similarly, magenta added to green produces white light, therefore magenta and green are complementary; and yellow added to blue produces white light, therefore yellow and blue are complementary.

SUBTRACTIVE COLOR MIXTURE

A cyan filter passes blue and green light, but absorbs red light. In other words, it subtracts the primary red from white light. Similarly, a magenta filter passes red and blue, subtracting green from white light; and a yellow filter passes red and green, subtracting blue from white light. These effects are shown in the smaller illustrations of Fig. 2.

In our demonstration of additive color mixture we used three projectors, one fitted with a red filter, the second fitted with a green filter, and the third fitted with a blue filter. We would not place all three filters, or even any two filters, in the light beam of a single projector, since, because each of these filters transmits only one-third of the visible spectrum, no one of them will pass the light transmitted by either of the other two. This means that a combination of any two of these filters — red plus blue, red plus green, or blue plus green — placed in the path of a single light beam, will absorb all the light.

With magenta, cyan and yellow filters, however, this is not the situation. Each of these filters transmits *two-thirds* of the visible spectrum, subtracting only one-third. Let us see what happens if we combine these filters in pairs in the path of a single beam of white light:

Cyan + magenta:

> Cyan subtracts red, magenta subtracts green; *blue* light comes through.

Cyan + yellow:

> Cyan subtracts red, yellow subtracts blue; *green* light comes through.

Magenta + yellow:

> Magenta subtracts green, yellow subtracts blue; *red* light comes through.

Suppose, now, we insert all three filters in the path of a single beam of white light:

Cyan + yellow + magenta:

> Cyan subtracts red, yellow subtracts blue, magenta subtracts green; *no light* comes through.

These results are shown in the illustration at the upper left of Fig. 3. Here we can see that the combined subtractions of all three filters (where all three overlap) result in black, because no light gets through. The combined subtractions of *any pair* of these filters, however, result in one of the additive primaries. Here then, by using magenta, cyan and yellow filters to subtract a part of the visible spectrum from a single source of white light, is a method for controlling the red, green and blue light to which the receptor mechanisms of the human eye are sensitive.

Clearly then, cyan, which subtracts red light from white light, can be used in varying amounts to control the amount of red light reaching the eye. Similarly, magenta can be used to control the amount of green light, and yellow to control the amount of blue light reaching the eye. So, the colors *magenta, cyan* and *yellow* are known as the *subtractive primaries.* As in the case of additive color mixing, the subtractive primaries can be used in various proportions to produce a wide variety of colors.

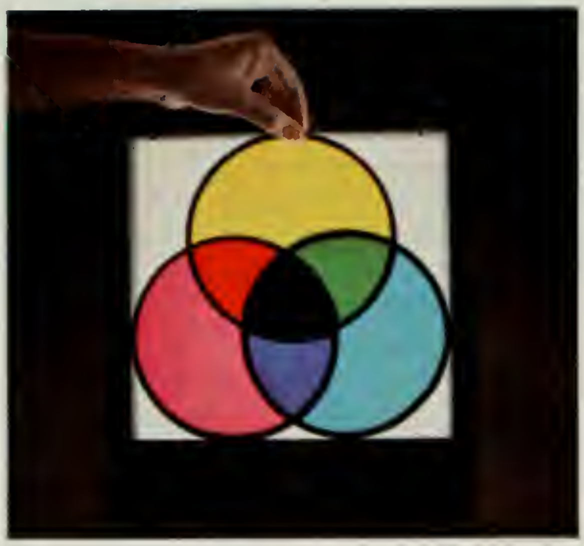
All the currently successful motion-picture color processes depend upon the principle of subtractive color mixture. Live color television, on the other hand, uses the principle of additive color mixture. A color television program on film makes use of both principles — the color film being subtractive while the color TV picture tube is additive in nature.

Now let us return to our set of water color paints. As we noted earlier, when we consider pigments or paints we are dealing with mixtures of colored light *as reflected from these substances.* A color pigment is actually made up of millions of tiny particles that act as magenta, cyan or yellow filters to control the amounts of red, green and blue light reaching the eye. Take the case of a green house, for example. Sunlight (white light) falls on the "green" paint. This paint contains millions of tiny particles which absorb the red and the blue wavelengths of the sunlight, but reflect the green wavelengths back to our eyes. The pigment in a green paint is therefore a mixture of millions of particles which are in effect tiny cyan and yellow filters.

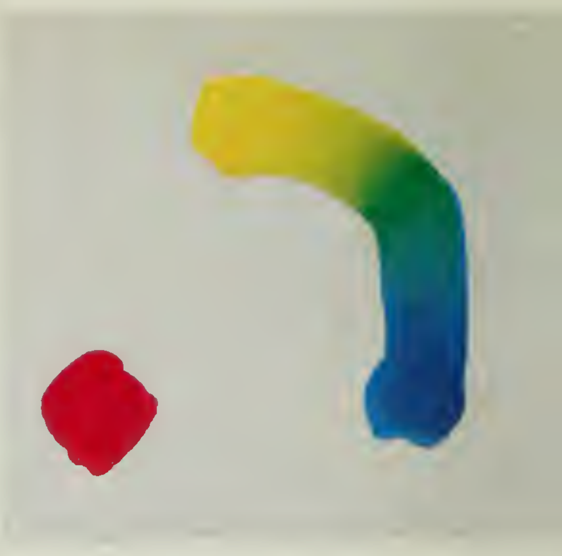
As everyone who has used a set of paints knows, a large variety of colors *can* be produced by making appropriate mixtures of three suitably chosen primaries commonly called "red," "blue" and "yellow." If this range of colors is to be at all complete, however, the "red" will really be a magenta, and the "blue" will really be a cyan. It is unfortunate that the quoted names have been used so often, because their use in this loose fashion has undoubtedly acted as a bar to the more widespread understanding of the principles of color mixture.

Suitable magenta, cyan and yellow water colors are shown in Fig. 3. In the illustration at the upper right, cyan and yellow paints have been mixed to produce green, just as they did when filters were used. The larger illustration shows the full range of colors produced by this set of subtractive primaries. Toward the center the white paper shows through more and more as it is covered by less and less of the colored pigments, and the colors become progressively lighter until no pigment covers the paper and we see white.

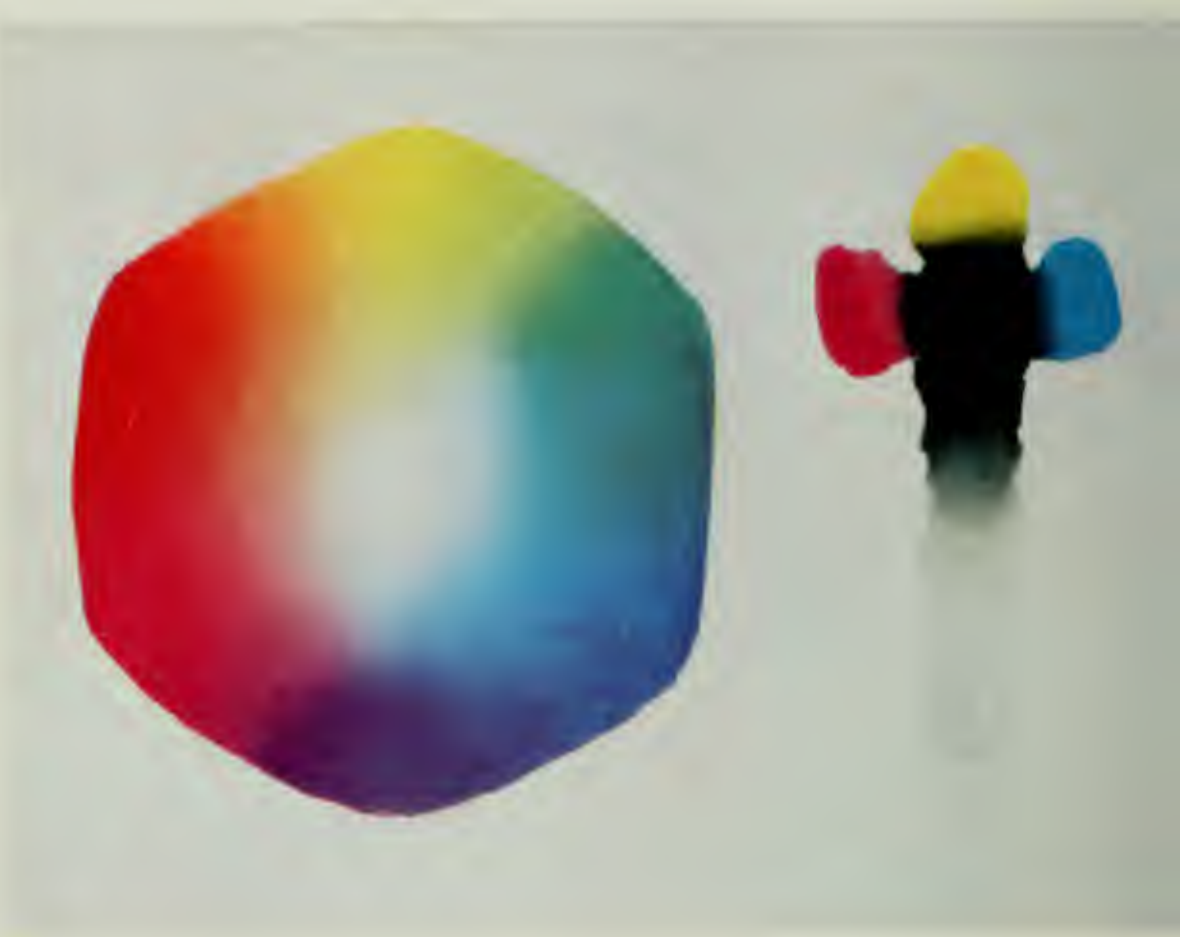
Also shown in Fig. 3 is a scale of neutral grays obtained by mixing magenta, cyan and yellow in the proportions required to produce black, but in smaller quantities as they scale away from the black. Here again, as in all subtractive color mixtures, the subtractive primaries are used to control the red, green and blue light reaching the eye.



Cyan, magenta and yellow filters partially superimposed. The combined subtractions of the filters in pairs give red, green and blue. Where all three filters overlap, no light is transmitted.



Cyan, magenta and yellow water colors
Cyan and yellow have been mixed t
make green, just as they did when fil
ters were used. Other colors obtaine
with these primaries are shown below



The range of colors produced by mixing the primaries at the upper right in varying propor
tions. Toward the center, the quantities were decreased, and the white paper shows throug
more. At the right, all three primaries were mixed in the proportion required to produce
neutral, but in varying amounts. The result is black shading through a scale of grays to white

FIGURE 3 (Courtesy Eastman Kodak Company)

3. Characteristics of Color

PRODUCTION OF COLOR

There are a number of ways in which color can be produced. Let us examine briefly those which are more important in practical color photography.

Absorption

The colors of most ordinary objects are due to the fact that they absorb different amounts of light of different wavelengths. We have already seen that a "green" filter looks green because it absorbs from white light all wavelengths except those which give rise to the sensation which we call green. The color of an object such as a green blotter is produced in similar fashion. In both cases the coloring material has such a physical structure that it absorbs red and blue light.

The surface of the blotting paper is an irregular arrangement of translucent fibers which have been treated with the coloring material. Light penetrates fairly deeply into these fibers, and, before being reflected to the eye of an observer, it has passed through several of these fibers and the coloring matter has absorbed the red and blue wavelengths of the original white light. Thus the blotting paper appears green, and the color is due to absorption. Many other surfaces, whether rough or smooth, act in the same way — light falling on them penetrates far enough to undergo the absorption which is characteristic of the surface, then is returned to the observer to cause him to identify it as a particular color.

Surface Characteristics

A few materials, chiefly polished metals like gold, copper or brass, have the property of selective reflection at their front surfaces. This property gives rise to "surface" or "metallic" colors as distinguished from the more common "body" or "pigment" colors. Certain brightly colored insects and the crystals of some organic chemicals also exhibit this type of metallic coloration.

Scattering

The color of the blue sky is due to scattering of sunlight by the atmosphere. Variations in the density of the atmospheric gases act in such a way that they scatter the shorter wavelengths at the blue end of the spectrum much more than they scatter the longer wavelengths. When the air is dusty, or contains water in the form of droplets or ice crystals, more of the longer wavelengths are also scattered. The sky is bluest, therefore, when the atmosphere is clearest, and whiter when the atmosphere is less clear. If there were nothing in the atmosphere to scatter light, the sky would always be dark and the stars would be visible at any hour, day or night.

Scattering of light by the atmosphere is also responsible for the reddish appearance of the sun when it rises or sets. When the sun is high in the sky, the direct rays pass through the atmosphere without noticeable subtraction of the blue light by scattering, even though enough of these short, blue wavelengths actually are scattered to make the sky appear quite blue. (This is another example of the eye compensating for relatively small changes in the color quality of illumination.) Early or late in the day, however, when the sun's rays strike the earth much more obliquely, they must pass a much greater distance through the atmosphere. At these times, depending on how high the sun is above the horizon and the sizes of the particles present in the atmosphere, light of longer and longer wavelengths is scattered, and the sun appears yellow, orange, or even a fairly deep red. This same phenomenon also causes the moon to change color from deep orange or yellow to white as it rises and climbs higher in the sky.

On a sunny day, distant mountains appear a hazy blue, lacking in detail, because the blue light resulting from atmospheric scattering between the observer and the mountains is superimposed on the light reaching the observer from the mountains themselves. Any distant object on the horizon is seen in this same fashion — through a veil of haze which strongly affects its appearance.

Some other colors in nature are due to this same cause. Blue feathers, for example, often are blue not because they contain a blue pigment, but because finely divided particles suspended within a translucent framework scatter blue light more effectively than light of longer wavelengths. Scattering also explains why veins close to the skin are bluish rather than reddish, as might be expected from the color of the blood. There is no reflected light from the deeper tissues. The only light reaching the eye is the blue light scattered by the vein wall and the skin layers just above it.

Interference

Color can be produced in thin films of unequal thickness by a physical phenomenon known as interference. Familiar examples are a soap bubble, and a film of oil floating on water. Under such conditions a light ray reflected from the bottom surface of the film travels a slightly greater distance than a parallel ray reflected from the top surface. This causes waves of some wavelengths to be weakened more than waves of other wavelengths because the troughs of one wave cancel out the crests of another. The reflected light is therefore colored, even though the film is illuminated by white light and contains no color-absorbing materials. The colored patterns known as *Newton's Rings,* which sometimes cause trouble in the printing of motion-picture film, are due to interference.

Fluorescence

The use of "fluorescent" materials in stage costumes is well known. In such a material the molecules of the fluorescent material absorb radiant energy of one wavelength and re-radiate it as another wavelength. Sometimes the radiant energy absorbed is not a part of the visible spectrum, as in the case when so-called "black light" is used. Here, with the normal stage lighting turned off, costumes are made to glow in the dark under ultraviolet radiation from lamps covered by filters. These filters absorb the visible radiation and transmit the ultraviolet radiation. Fluorescent dyes in the costumes absorb the invisible ultraviolet radiation and return some of it to the eye of an observer as visible radiation. Different fluorescent dyes will radiate different wavelengths of light after absorbing the ultraviolet radiation, so that quite a gamut of colors is possible by using this technique.

This same principle was used during World War II in the manufacture of colored signalling fabrics. These materials could be seen from remarkable distances because of the intense coloration produced by the fluorescent dyes. As a matter of fact, a number of fluorescent dyes are regularly used in the textile industry because they extend considerably the range of colors which can be made available in finished cloth.

One interesting point may be made here in connection with the expression "black light." This, together with such common expressions as "infrared light" or "ultraviolet light," is, by definition, incorrect. By definition, all light is visible, and wavelengths which are not visible cannot be light. We should therefore speak of "ultraviolet radiation," for example, instead of "ultraviolet light." For the same reason the word "visible" is superfluous in the commonly used expression "visible light."

Dispersion

Dispersion is the production of color caused by differences in the refractive or bending power of a transparent medium for different wavelengths of light. The rainbow, caused by light passing through transparent water droplets, is an example of color produced by dispersion. The spectrum of Fig. 1, formed by passing light through a transparent glass prism, is another example. In each of these instances, as in all cases where color is produced by dispersion, the color results from the fact that the shorter the wavelength of light, the more it is bent by a transparent medium such as water or glass. Thus a beam of white light is separated into a series of side-by-side wavelengths, the short wavelength blues having been "refracted" the most and the long wavelength reds the least. The flashes of color seen when a cut and polished diamond is viewed under a concentrated light source are also due to dispersion.

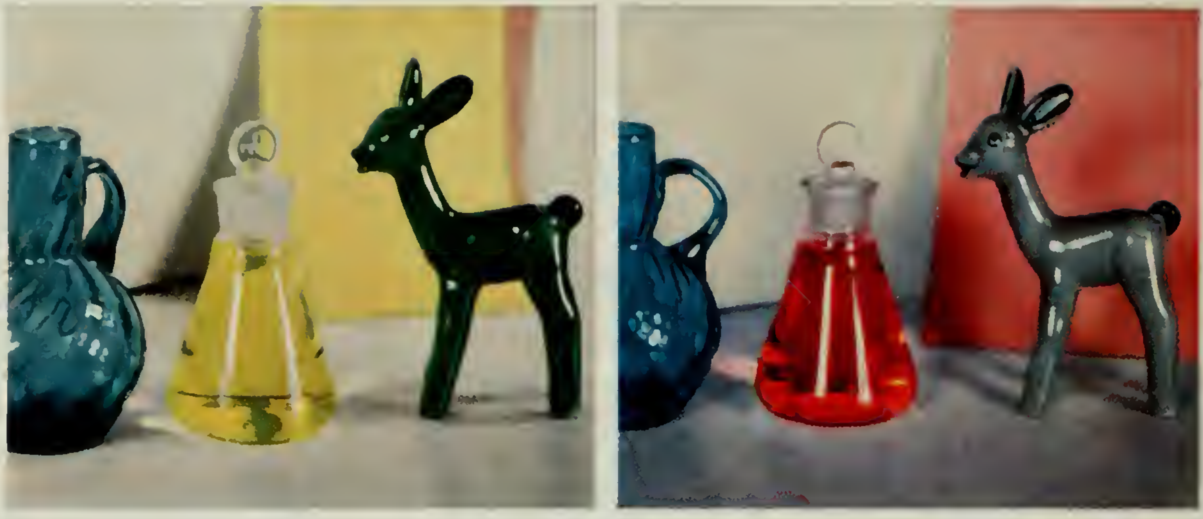
EFFECT OF LIGHT SOURCE AND VIEWING CONDITIONS

As we have seen, light sources vary as to color quality. This variation, known as a difference in *spectral energy distribution,* causes the quality of light reflected from colored objects to vary when these objects are illuminated by different light sources. As a result, the visual stimulus reaching the eye will vary, and the visual sensation produced when viewing colored objects will depend to some extent on the color quality of the illumination.

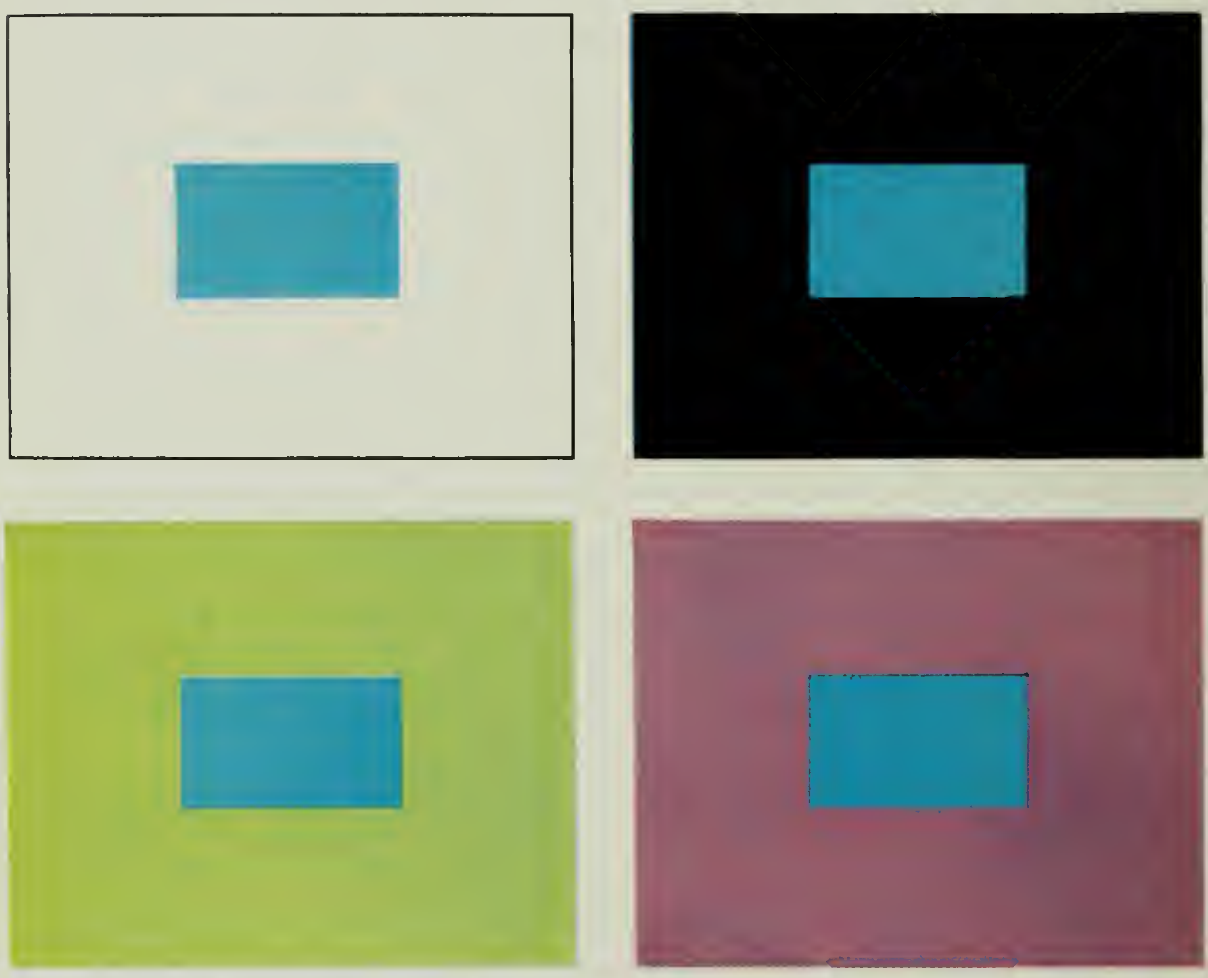
We have seen how the human eye will adapt itself, accepting either daylight or tungsten light as white, provided the two are not intermixed. A further tendency to compensate is shown whenever a colored object is viewed under different types of illumination, even though the selective reflectivity of a colored object usually tends to exaggerate color differences in illumination. A visual phenomenon known as *approximate color constancy* (which we shall discuss later in more detail) is responsible for this tendency for colored objects to appear identical under different types of illumination. If, however, the light sources or the reflecting surfaces of the colored objects are extremely selective with respect to wavelength, a change in appearance of these objects is often quite noticeable.

Certain types of fluorescent lamps are relatively so rich in some wavelengths and so poor in others that they exert a marked influence on the apparent colors of objects. The illustrations at the top of Fig. 4 show this quite clearly. Similarly, the appearance of fluorescent dyes is likely to change noticeably when the light source is changed. With the introduction of a number of fluorescent textile dyes, it is not uncommon to find fabrics which change color to a much greater extent than other objects.

Surroundings can also affect our visual judgment of colors, sometimes to a much greater extent than variations in light sources. In the lower four illustrations of Fig. 4 the central patch of color is physically identical in all cases, yet its appearance is strikingly different. Obviously, then, to establish a relationship between the physical characteristics of a surface and the visual sensation it arouses, we must



The color of an object may appear different under two different illuminations, even though the light sources themselves are a visual match. At the left the scene is illuminated by the white light of an incandescent lamp. At the right the light is also white and would appear exactly the same as at the left, but it consists of narrow bands of energy in the blue-green and red portions of the spectrum.



The apparent color of any object is affected by the color of its surroundings. If isolated, the central patch would be seen to have exactly the same blue-green color in all four illustrations. At the upper right the patch appears lighter than at the upper left. At the lower left it is intermediate between the upper two in lightness and more bluish than either. At the lower right it is intermediate in all respects.

FIGURE 4

(Courtesy Eastman Kodak Company; reprinted with permission from Ralph M. Evans's *An Introduction to Color*, 1948, John Wiley & Sons, Inc.)

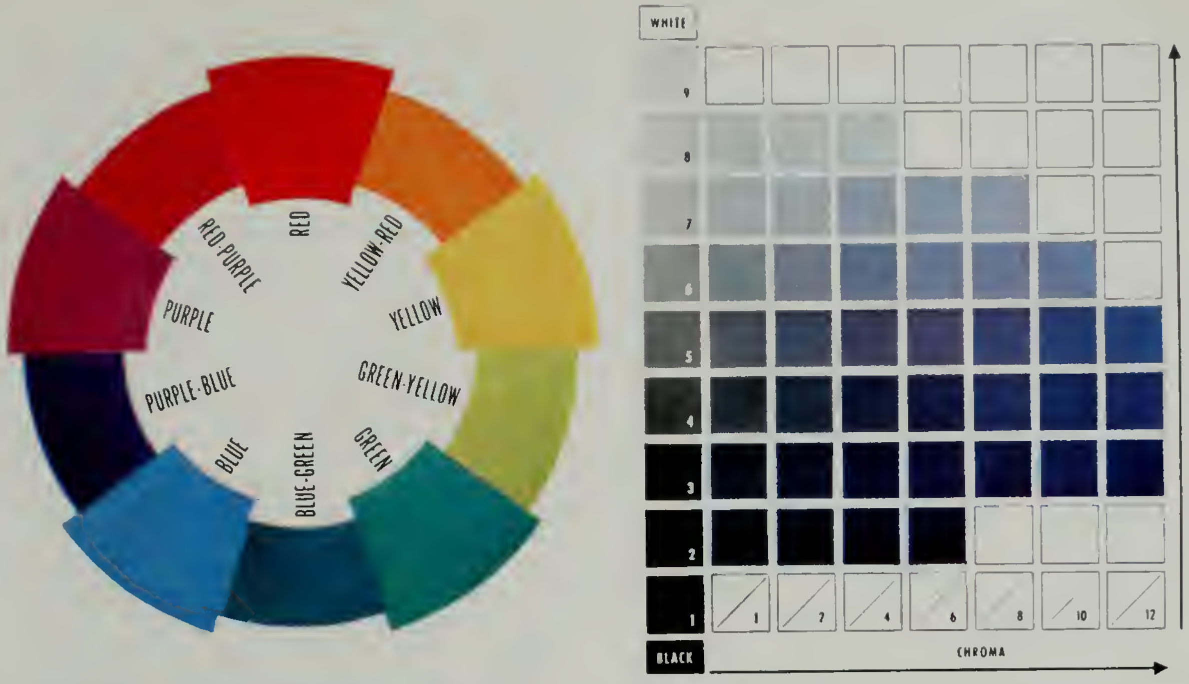
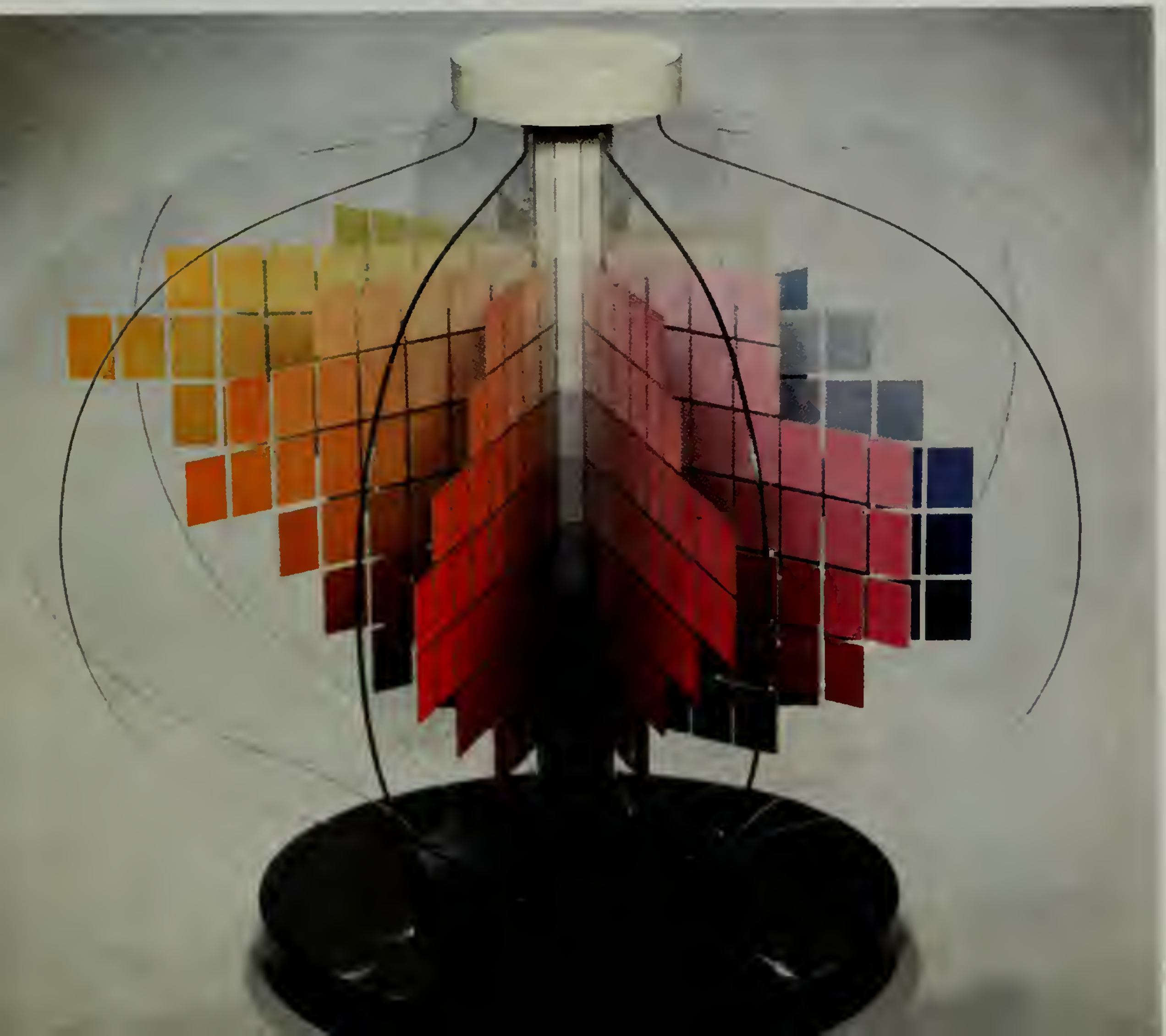


FIGURE 5: The Munsell System.

(Left) Hue circle showing the Principal Hues. Each is number 5 of a family of 10 adjoining hues. (Right) Chart showing all variations in value and chroma for 5PB. The gray scale shows the steps between theoretical black and theoretical white. (Below) Color tree showing the three-dimensional relationship of hue value and chroma. (Courtesy Eastman Kodak Company; illustrations and color papers by Allcolor Co., Inc., industrial designers and consultants, New York.)



take into account the viewing conditions.

COLOR AS A SENSATION

According to the modern, scientific definition of color, it is not correct to relate color to an object, but only to the light reflected from this object. This light gives rise to a visual sensation, the attributes of which we can describe.

If we are asked the color of an object such as a sweater, our first reaction may be to say, for example, that it is red. When we do so we are referring to the capacity of the surface of the yarn to modify the color of the light falling on it, so that only red light is reflected to our eyes. By this means we identify the *hue* of an object — that is, whether it is red, or yellow, or purple, or some other "color."

Nevertheless, we are conscious, at least in a vague sort of way, that this description is inadequate. In an effort to be more specific, we may say that the sweater is "light red," or "dark red." When we do this, we are describing the brightness of a color. If we stop to think about it, we realize that this characteristic is independent of the hue; that is, we can have two colors which are the same hue, but of different brightness.

We might also say of the sweater that it is a "dull" red, or a "bright," "vivid," or "brilliant" red. Here we are attempting to describe still another characteristic of a color — its *saturation*. The saturation of a color may be regarded as a measure of the extent to which it departs from a neutral, or gray, of the same brightness.

A further example may serve to clarify these concepts of hue, saturation and brightness. Suppose we have several pails of gray paint, ranging from a very light (almost white) gray through darker and darker shades to a very dark (almost black) gray. We know that these gray paints are gray because they show no selective reflection for any particular portion of the visible spectrum. They may reflect strongly, as in the case of the light gray; moderately, as in the case of the medium gray; or weakly, as in the case of the dark gray. Nevertheless, whether they reflect strongly, moderately or weakly, they reflect approximately equal amounts of all the visible wavelengths.

Suppose, now, we select that pail of paint which is just darker than white — a so-called "off-white" shade of gray. This is a very light gray, reflecting quite strongly all the visible wavelengths. Its *brightness* is thus high. Being a neutral gray it does not, however, possess the attributes of *hue* or *saturation*. Suppose, now, we begin to add small quantities of a certain blue pigment to this gray paint. It now becomes a faintly bluish gray, possessing attributes of *brightness, hue and saturation*. From a neutral gray paint of high brightness, no hue and zero saturation, it has become a blue paint of high brightness, a certain blue hue, and low saturation. If we add more blue pigment we increase the saturation, making the paint more blue and less gray. The hue remains unchanged as long as we continue to add the same blue pigment. The brightness, however, has decreased because the blue pigment is now absorbing some red and some green light which was being reflected when the paint was light gray. Thus by increasing the saturation of a color we decrease the total amount of light reflected, irrespective of wavelength, and so decrease the brightness. We will find this condition to be generally true for any subtractive color mixture — for any given hue, the greater the saturation the lower the brightness.

If we had started our experiment with one of the pails of darker gray paint, our results would have been the same. Having used the same blue pigment, our resulting paint would have been of identical hue and saturation for any specific amount of pigment added. The brightness of this darker gray paint would have been lower from the start, however; and, as in the case of the lighter paint, it would continue to decrease with each addition of pigment.

We usually experience little difficulty in detecting hue differences between colors, but we frequently become confused when judging brightness and saturation differences. We find ourselves unable to decide whether two colors differ only in brightness, or whether their saturation is also different. This fact is of some importance in color photography, because it affects our judgement of color rendering. For example, an excessively deep blue sky in a color picture may give the impression of high saturation when the real difficulty is low brightness, If, however, the reproduction of the sky is compared with a blue filter, the relatively low saturation in the blue sky is immediately apparent. This confusion between saturation and brightness is typified by the frequency with which the word "bright" is used in everyday speech to describe a highly saturated color.

SYSTEMS OF SPECIFICATION

Frequently we attempt to describe a color more or less completely by a single term, sometimes by the name of some object which is more or less familiar to everyone. For example, pink, cherry, cerise, rose, scarlet, vermilion, crimson and rust are all used to describe various reds. The difficulty is that each term means one thing to one person, something else to another person. We would all agree that "pink" describes a red which is high in brightness, low in saturation, and somewhat blue-red in hue. Even within these limitations, however, there are many possibilities. We certainly would not think of buying yarn to complete a half-finished sweater, specifying only that it was to be "pink." Instead, we would match the two yarns directly; and with a little experience in judging color, we would also make sure that the two yarns matched both in daylight and in artificial light.

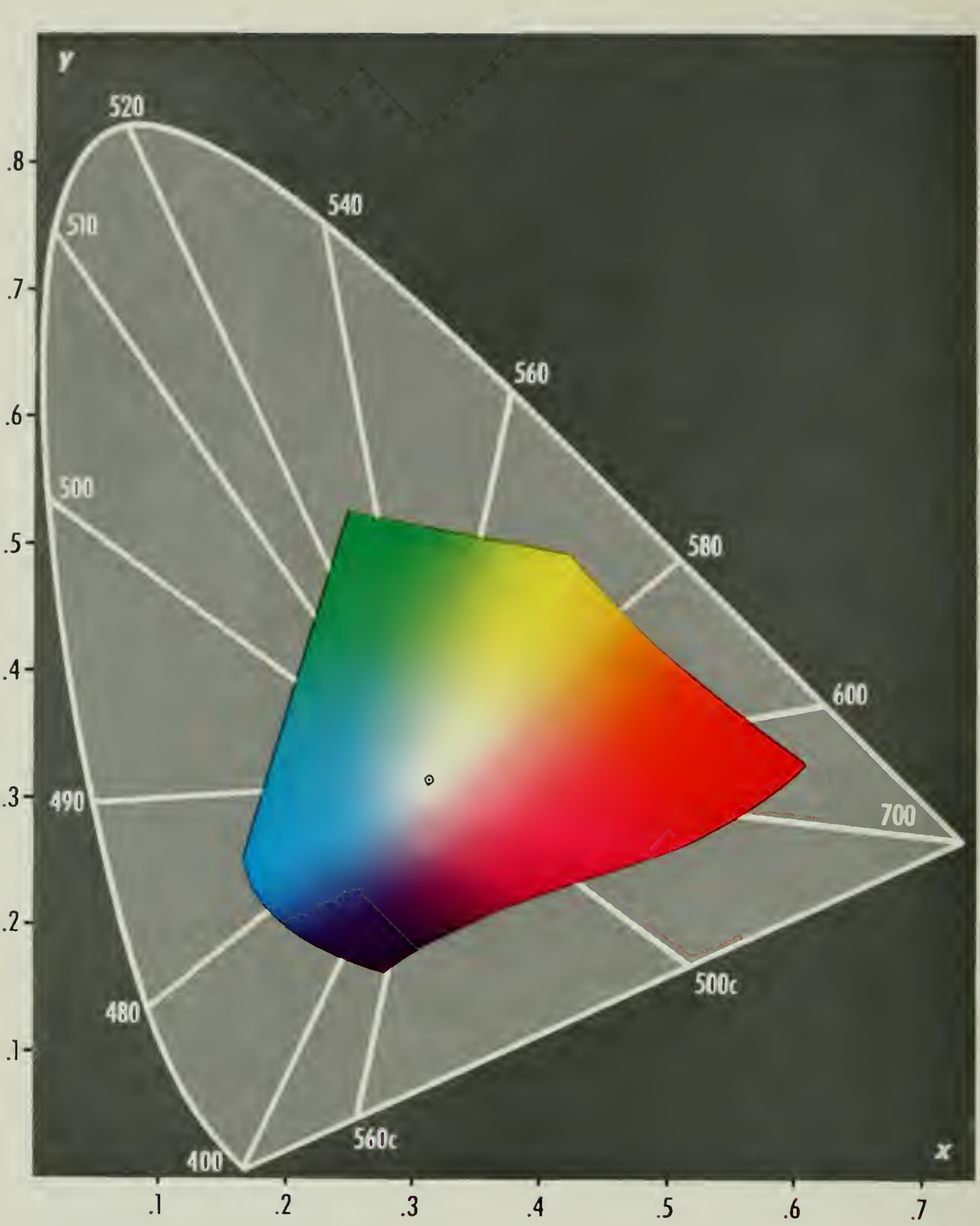
The need for an accurate language to describe color becomes great when, as often happens, circumstances do not permit direct comparisons. Actually, we do not have a universal color language; but we do have systems of color specification and notation which answer most of our needs. Outstanding among these are the *Munsell System* and the *CIE System.*

Munsell System

Essentially, the Munsell System is an orderly arrangement into a three-dimensional solid of the colors which can be represented by actual surface samples prepared from stable pigments. The general shape of the solid is shown in Fig. 5. The various hues are spaced horizontally around a circle which is divided into ten major hues.

CIE System

The CIE System of color specification, so designated because it is based on recommendations of the Commission Internationale d'Eclairage (International Commission on Illumination), specifies colors in terms of the amounts of the additive primaries necessary to match a color in question. In Fig. 6 is shown the *chromaticity diagram* of the CIE System (until recently, known as the ICI System), which forms what might be described as a map of all possible colors. The horseshoe-shaped boundary represents the positions of the colors which have the highest possible saturation — the spectrum colors. The colored area represents the limits of saturation possible with a set of modern printing inks.



CIE CHROMATICITY DIAGRAM—On this "color map," the horseshoe-shaped boundary line around the light gray area shows the positions of the pure spectrum colors. Some of these are identified by their wavelengths in millimicrons. The straight line closing the horseshoe shows the positions of the magentas and purples, which are complementary to the greens of the spectrum. The edge of the colored area shows the purest colors which can be printed with a typical set of modern process inks. Near the center of this area is the "illuminant point" for the standard light source equivalent to daylight; this is also the position of any neutral gray illuminated by daylight. By simple mathematics, the spectrophotometric curve of any color sample can be translated into values of x and y. The position of the color can then be plotted on the diagram to show its relationship to all other colors.

FIGURE 6 (Courtesy Eastman Kodak Company.)

4. Color Films and Processes

We have seen that practically any color can be matched by mixing red, green and blue light in suitable proportions. We have also seen that the human eye sees all colors by breaking them down into their red, green and blue constituents. This characteristic of human vision defines the fundamental requisites of a motion-picture color process, which, as a matter of practicality have been found to be as follows:

(1) Separation of all colors in an original scene (including black, white and neutral grays) into individual red, green and blue records by means of "original camera" films.

(2) Incorporation of fades, dissolves and other required "effects" by means of rephotographing the camera original films onto "intermediate" films.

(3) Recombination of the red, green and blue camera records on a final, "viewing" film, thus reproducing the original scene.

We may list, then, three distinct types of films:

(1) *Camera original films* — relatively high-speed films used in a camera for original photography.

(2) *Intermediate films* — low-speed, high-definition films used for copying or duplicating camera original films.

(3) *Release positive films* — relatively low-speed, high-definition films used for producing a final, "viewing" print for screening or televising.

CAMERA ORIGINAL FILMS

We have seen that all color processes have the problem of resolving the various colors of an original scene into separate records of the red, green and blue constituents of those colors. The only practical way in which this has been accomplished has been to provide three separate photographic emulsions, one to record each of the additive primary colors. In order to restrict each of these emulsions to only one primary color it may be made sensitive to only one of the primaries, or it may have its sensitivity confined to the proper region of the spectrum by a filter. These three emulsions may each be coated on a separate film support, so that three separate films are used to photograph the red, green and blue records of a scene, or they may all be coated on a single film support, constituting what is known as a "multilayer" color film.

Three-Strip Negative

When color motion pictures are photographed on three separate films they are said to be photographed by the "three-strip" method. A special camera is required in order to expose the three films simultaneously to exactly the same scene, and the only camera in which this has been successfully done on a commercial basis is one manufactured and furnished by the Technicolor Corporation.

This camera is unique, employing a

special "beam-splitting" prism block shown in Fig. 7. The green components of the light coming from a scene are transmitted through the camera lens and the light-dividing prism, and recorded on a negative film which is particularly sensitive to green light. The red and blue components pass through the same lens and enter the same light-dividing prism, but instead of being transmitted they are reflected to an aperture on the side of the camera. In this aperture two films are traveling together, emulsion to emulsion. The front film (nearest the prism) records the blue components of the scene, while the rear film records the red components.

When developed, these three films contain silver images which look very much like the silver images on any ordinary black-and-white motion-picture negative. Closer inspection, however, will reveal the fact that the silver density resulting from the light reflected from any particular colored object varies considerably among the three negatives. A purple dress, for example, will produce density on the red and blue negatives and essentially none on the green, since purple objects reflect red and blue light while absorbing green light. A set of Technicolor three-strip negatives is shown in Fig. 8(a).

Multilayer Color Negatives

If the red, green and blue recording emulsions are coated superimposed on a single film base, and these three emulsion layers yield negative *color* images when developed, we have what is known as a "multilayer color negative" film. The color images of a multilayer color film are composed of organic dyes, instead of silver images such as we found on the three-strip negatives. This is necessary in order that we can control the characteristics of each of the three emulsion layers independently of the other two, and so keep the three layers in balance. If the emulsion layers can be isolated physically, as they can when coated on separate film supports, it is possible to use black-and-white images to record the red, green and blue aspects of a scene. If the three emulsions are coated on a single support and cannot be physically separated from one another, some way must be found to allow the information contained in each layer to be translated to the print material in such a manner as to produce the proper amounts of dyes in the print. This is impossible if silver images are used. However, if color images are used, the three records can be printed separately onto the color positive material by the use of filters.

In the films containing dye images, subtractive primary colors (cyan, magenta and yellow) are used to vary the red, green and blue components of a single light source. Sometimes this is a printing light; sometimes it is a light used to illuminate the film for viewing. The amount of cyan dye present determines the amount of red light which gets through the film, since cyan subtracts red light from white light, passing blue and green light. Likewise the amount of magenta dye present controls the amount of green light transmitted by the film, since magenta subtracts green from white light, passing red and blue; and the amount of yellow dye present controls the amount of blue light transmitted by the film, since yellow subtracts blue from white light, passing red and green. (Refer again to the discussion on subtractive color mixtures.)

In a multilayer color negative film the top layer is blue sensitive only, and records the blue constituents of all colors in a scene. The second layer records the green, while the bottom layer records the red color constituents.

In the United States, the most widely used multilayer color negative films are

Eastman and *Ansco*. In Europe, *Agfacolor, Gevacolor* and *Ferraniacolor* are also used. An Eastman color negative is shown at Fig. 8 (b) and an Ansco color negative at Fig. 8 (c). The overall orange color of the Eastman film results from color "masks" which are used to compensate for certain deficiencies inherent in all photographic dyes. No such mask is used in the Ansco negative. Neither is one used in the Agfacolor, Gevacolor or Ferraniacolor negatives, shown in Figs. 8(d–f), respectively. It is reported that a mask will be used in the color negative film now under development by Du Pont.

Multilayer color negative films have the advantage of requiring no special intricate camera for their use. Because they can be exposed in a conventional black-and-white camera, they have become increasingly popular.

Multilayer Color Reversal Positives

Some multilayer color films can be processed so that a positive rather than a negative color image results. Such films are known as color *reversal* films.

Until just recently, the only 16mm color reversal film used in professional color motion pictures has been Kodachrome film. Another material, Anscochrome Professional Film, has now also been made available.

Industrial and educational pictures are usually made on 16mm film; and for expedition photography, especially in rough country, the light weight of 16mm equipment is often a requisite. A Kodachrome 16mm color reversal film is shown in Fig. 8 (g).

Successive Frame Negatives

There is one type of camera original film currently used in professional color motion pictures that does not require three separate emulsion layers to record the red, green and blue constituents of the various colors in a scene. This is the "successive frame" negative — a single black-and-white negative film on which the red, green and blue color records are exposed sequentially, through filters, rather than simultaneously. Use of this type of camera original film is limited, however, in that it can be applied only to the photography of stationary objects. If the object being photographed moves even slightly between exposures the successive red, green and blue images will not register — that is, they cannot be superposed exactly in the final viewing print. Lack of register in a color print results in fringes of false color around the outlines of objects.

The principal use of successive frame negative film is in animated cartoons, most of which are produced by this method. A successive frame negative is shown in Fig. 8 (h).

INTERMEDIATE FILMS

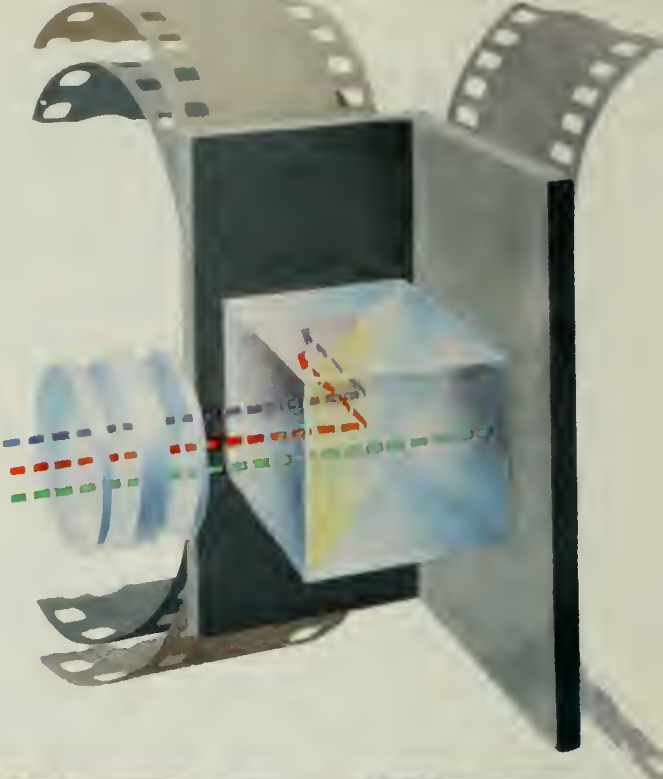
In color, as in black-and-white motion-picture practice, there are both *master positive* and *duplicating negative* intermediate films.

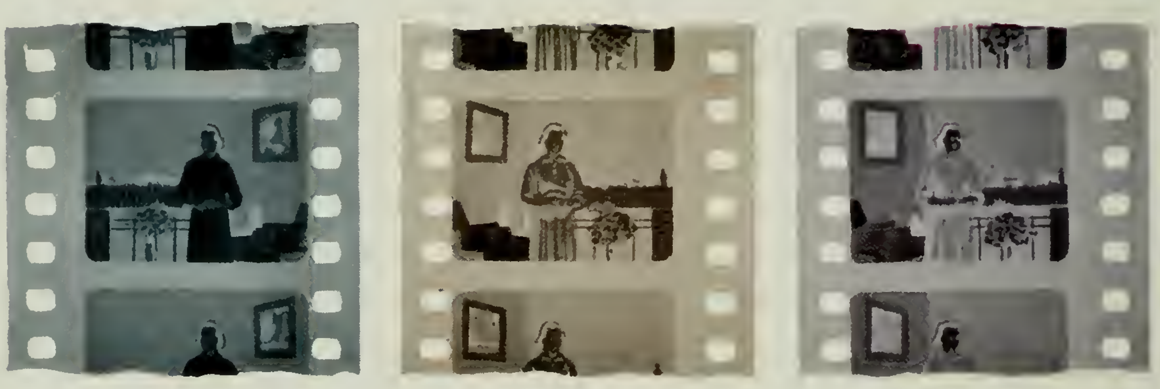
Master Positives

As in black-and-white motion-picture practice, a master positive print is often made from a color camera original film as soon as practicable, as a protection against damage to the camera original film. This is especially true in the case of very expensive pictures, or an original negative which might be irreplaceable if lost. In some photographic color motion-picture processes, "masters" are a necessary step in the production of duplicate negatives containing the dissolves, fades, and other "effects" required in the final exhibition print.

At present, all master positive films available for printing color separations from multilayer color negatives are fine-grain, high-definition, panchromatic (sensitive to all colors), black-and-white films. Three separation masters

Fig. 7. The Technicolor Three-Color Camera uses three strips of negative film and incorporates a special prism in the optical system to divide the light. Two of the films, with the emulsion surfaces in contact, are placed in the camera at a right angle to the camera axis. The front film receives the BLUE image, and the rear film receives the RED image. The third film is placed directly in back of the prism and receives the GREEN image.





RED IMAGE BLUE IMAGE GREEN IMAGE

Fig. 8(a). TECHNICOLOR THREE-STRIP NEGATIVE: The Technicolor Three-Strip Negatives are silver images of the primary color constituents of a scene. Each film is composed of a single black-and-white emulsion coated on a single film support.

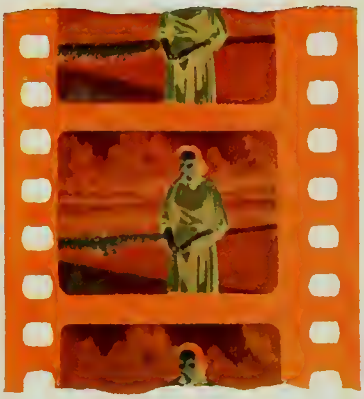


Fig. 8(b). EASTMAN COLOR NEGATIVE.

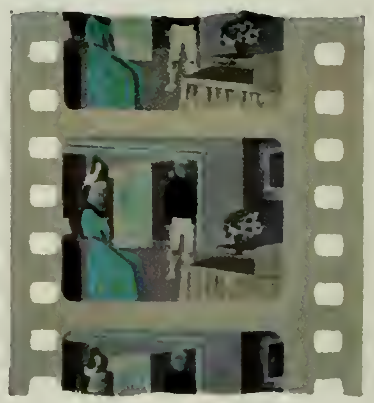


Fig. 8(c). ANSCO COLOR NEGATIVE.

FIGURES 7 AND 8 (Courtesy Technicolor Corporation.)

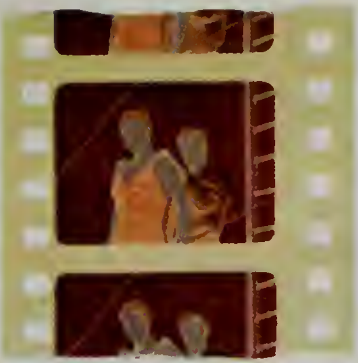


Fig. 8(d). AGFACOLOR.

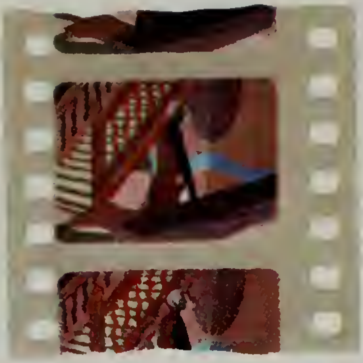


Fig. 8(e). GEVACOLOR.

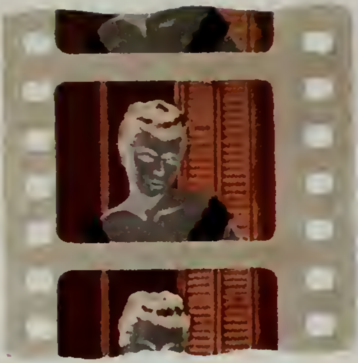


Fig. 8(f). FERRANIACOLOR.

Fig. 8(b–f). MULTILAYER COLOR NEGATIVES: Eastman Color, Ansco Color, Agfacolor, Gevacolor and Ferraniacolor Negative all have one strip of film coated with three superimposed layers of emulsion, each layer being sensitive to a different primary color. These films can all be used in a conventional 35mm camera.

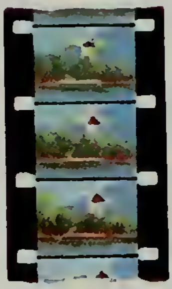


Fig. 8(g). KODACHROME: Similar to color negative, 16mm Kodachrome film has three layers of emulsion coated on a single film support, each layer being sensitive to a different primary color — RED, GREEN and BLUE. It differs from color negative in that a positive color image is produced by reversal processing.

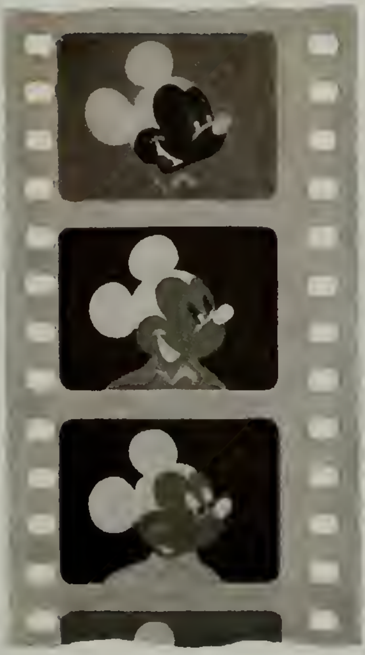


Fig. 8(h). SUCCESSIVE FRAME NEGATIVE: The Successive Frame Process, employed in most animated cartoon photography, uses one strip of black-and-white negative. In front of the camera lens is mounted a color wheel containing three filters — RED, GREEN and BLUE. The wheel rotates as each scene is photographed three times on successive frames, once through each of the three color filters. The Successive Frame Negative is therefore three times as long as the finished print.

FIGURE 8 (Courtesy Technicolor Corporation.)

are produced from the color camera original negative by rephotographing the negative once through a red filter, then through a green filter and finally through a blue filter. Except that these three films are positives rather than negatives, they correspond almost exactly to the three separation negatives produced in a three-strip camera.

A new color intermediate film intended for use as both a master color positive and a duplicate color negative has recently been announced by Eastman and will probably find extensive use in the future. Such a film offers significant economic advantages over black-and-white separation masters, since it enables a *single* color master positive to be produced from a color camera original negative. This eliminates the time-consuming procedure of having to prepare three separation master positives through filters. However, where long-term insurance against fading of originals or color masters is desired, black-and-white separation positives may still be required.

Duplicating Color Negatives

Duplicating negative films for professional motion-picture work are currently all of the multilayer color type. They are very much like color camera original negative films (with which they must be designed to be inter-cut), even to appearance. They are finer grain and slower speed films than camera original films, however. In some cases, also, a different arrangement of the sensitized layers and the dyes produced in them may be used to give improved definition.

A color "dupe" negative is either exposed directly from a color master positive or triple exposed, once from each of the separation masters through the appropriate red, green and blue filter, to provide a single, color negative copy of the color camera original, in which the necessary dissolves, fades and other "effects" have been incorporated. From this single, color dupe negative, a large number of color release prints can be printed at high speed.

Separation Matrix

This is a special kind of intermediate film, used only by the Technicolor Corporation. It is a film which is printed directly from three-strip negatives, or from a multilayer color camera original film through filters, to produce a red, a green and a blue separation matrix.

Separation matrices are unique insofar as they contain neither silver nor dye images after processing. Instead, they contain a gelatin relief image, much like a lithographic printing plate. These relief images soak up magenta, cyan or yellow printing dyes when immersed in dye solutions, and transfer these dyes to a special type of print film to produce Technicolor imbibition release positive prints.

RELEASE POSITIVE FILMS

Multilayer Color Positives

Multilayer color positives are films designed for viewing. They are companion films to the multilayer color camera negative films produced by the manufacturers already mentioned. One layer of a multilayer color positive film contains cyan, one contains magenta, and one contains yellow dye images. These dye images, as we have seen, determine how much of the red, green and blue components of the projector's light are transmitted by the filter. Multilayer color positives are used for turning out "daily" or "rush" prints by direct printing from a camera original color negative, and for making color release prints for theater or television exhibition. Multilayer color positive prints can be produced in much the same fashion and on the same equipment, with some modification, on which black-and-white release prints are made.

Imbibition Release Positives

These are special, single-emulsion, black-and-white films designed to imbibe the printing dyes transferred from the three separation matrix films just described.

Imbibition color release prints are manufactured only by the Technicolor Corporation. They are made by first removing all the light-sensitive silver halide from the picture area (the only silver in an imbibition color release print is in the soundtrack area). Then each of the dye-bearing matrix films, one after another, is brought in contact with the imbibition print film, so that the dye carried by each matrix is transferred to the print film. Thus the imbibition color release film undergoes three successive dye-transfer steps, one with each matrix. Each separation matrix transfers a dye which is complementary in color to the color record of the matrix. The red record matrix transfers the complementary cyan dye, the green record matrix transfers the complementary magenta dye, and the blue record matrix transfers the complementary yellow dye.

COLOR PROCESSES

A professional motion-picture color process may be defined as a "production" method of utilizing one or more of the several films just described, in an appropriate manner so as to make possible a large number of color release prints for exhibition purposes.

Strictly speaking, there are three distinct color processes in current use for professional color motion pictures:

(1) The Technicolor Imbibition Process;

(2) Multilayer Color Negative-Positive Processes;

(3) Multilayer Color Reversal Processes.

Technicolor Imbibition Process

This is the oldest and perhaps the best known of the currently used commercial color processes. Originally it made use of three-strip negatives to photograph a scene, and, from the separation negatives exposed in the Technicolor camera, three separation matrices and subsequently color imbibition release positive prints were made. Technicolor imbibition release prints have also been produced by using a 35mm multilayer color reversal film, similar to Kodachrome, as a color camera original film. This film, known as Technicolor Monopack, was then rephotographed through red, green and blue filters to produce three black-and-white separation negatives (just as separation masters are prepared from an original color negative). From these separation negatives, separation matrices were made by direct printing, and imbibition color positive prints were made in the customary manner.

The Monopack reversal camera original film possessed one of the advantages of the multilayer color negative films in that it required no special camera for its use. Color negative films, however, offer additional technical and economic advantages, and shortly after the introduction of color negative films, Technicolor discontinued the use of Monopack for original photography. Kodachrome 16mm color reversal film is still used, though infrequently, as a color camera original film from which color imbibition release prints are made. Its use is normally confined to photographing remote or hard-to-reach locations, where, as we have previously noted, the lighter weight and smaller size of the 16mm equipment is an important factor.

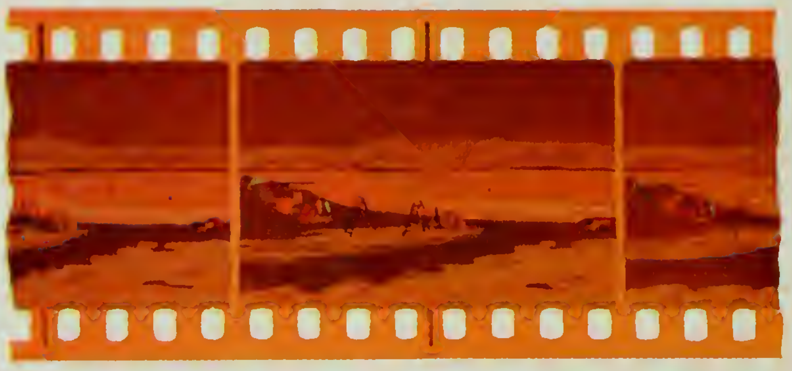


Fig. 9(a). VISTAVISION: In the VistaVision camera the film runs past the camera aperture horizontally, and an area corresponding to eight perforations (two normal frames) is exposed.

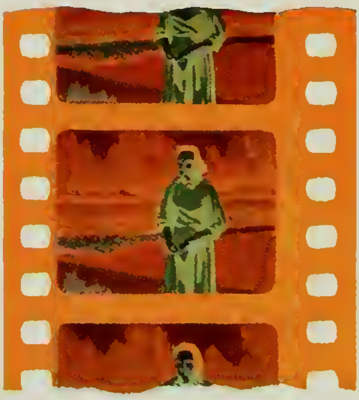


Fig. 9(b). STANDARD MOVIETONE: The normal movietone aperture is shown here for comparison.

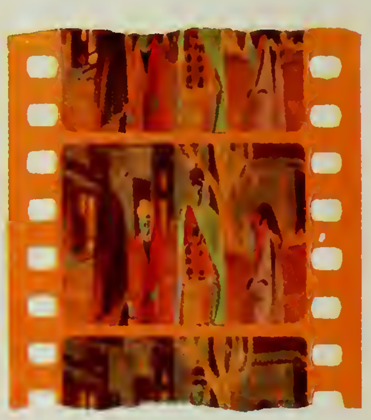


Fig. 9(c). ANAMORPHOSED IMAGE (CINEMASCOPE): The image is recorded on the film in the same manner as with other negative film processes, except that the image is compressed horizontally, that is, anamorphosed, by means of a spherical lens.

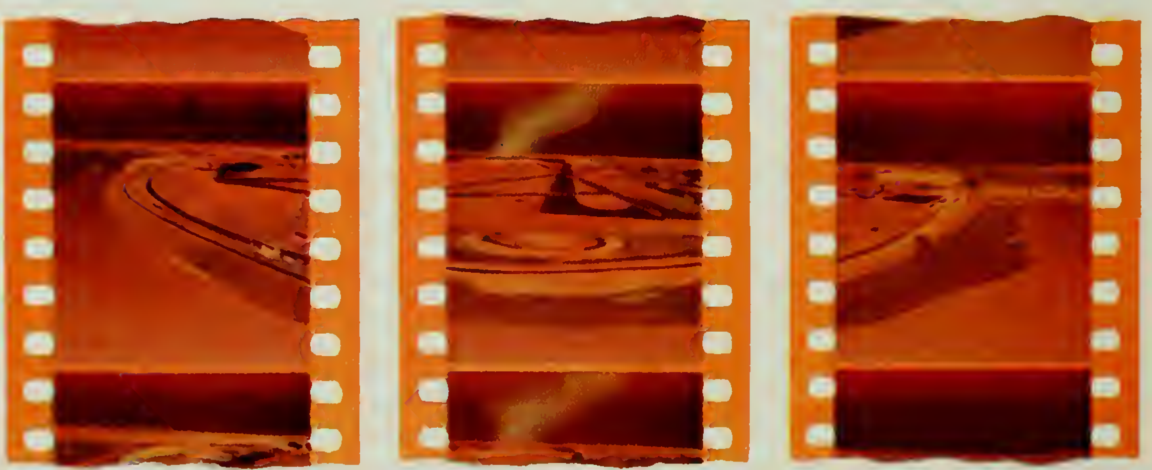


Fig. 9(d). CINERAMA: In Cinerama-type photography, 35mm color negative film is used, but a larger than normal area is exposed. On each of these negatives, which are exposed simultaneously in three separate cameras, an area corresponding to six perforations in height and extending completely across the film between the perforations is used.

FIGURE 9 (Courtesy Technicolor Corporation.)

Since the introduction of multilayer color negative camera original films, they have been used to photograph a great many pictures for Technicolor imbibition release printing. In fact, multilayer color negative has largely replaced three-strip negative as a camera original film for Technicolor imbibition release. From a color negative camera original film, three separation matrices are made — one through a red, one through a green and one through a blue filter. These matrices are then used to make imbibition color release prints.

Multilayer Color Negative-Positive Process

Since 1949 the multilayer color negative-positive process has enjoyed ever-increasing popularity. Original photography is done on a multilayer color negative film in an ordinary black-and-white camera. From this color camera original negative one of two procedures may be followed.

In the first procedure, three black-and-white separation master positives, one through a red, a second through a green and the third through a blue filter, are made for any scenes which require fades, dissolves or other "effects." These three separation positives are then printed, one after another and through the proper red, green or blue filter, onto a multilayer color "dupe" negative film, incorporating into this dupe the required "effects." The color dupe negative footage is then cut into the color camera original negative footage, and this "cut" negative is used to produce release prints by direct printing onto the proper multilayer color positive film.

In the second procedure, a color master positive may be made from the color camera original negative by printing onto a color intermediate film, as previously mentioned. A color duplicate negative is then made on the same material and the effects are incorporated at this stage. Release prints can then be prepared by printing the color duplicate negative onto the color release print stock.

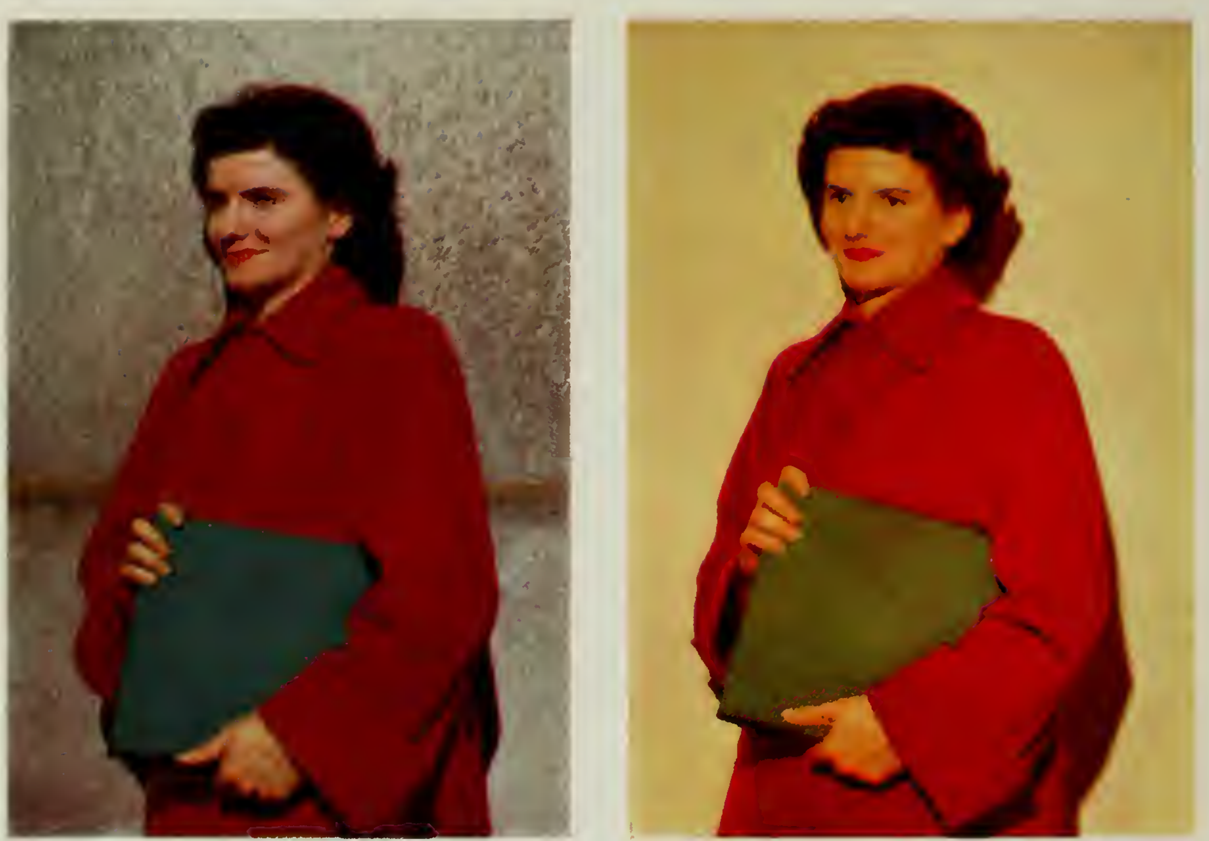
The color negative-positive process has acquired a variety of names. Some of these are the names of the film manufacturer, as "Eastman Color" or "Ansco Color." Some, such as "Technicolor," "Warner Color," "Pathecolor," "Trucolor," "DeLuxe Color," "Metro-Color," depend upon where the film is printed and processed.

To multilayer color negative films must go the credit for making possible the "new techniques" of color motion pictures, such as Cinerama, CinemaScope, VistaVision, and Todd-AO. Examples of each of these on Eastman Color Negative are shown in Fig. 9.

Multilayer Color Reversal Process

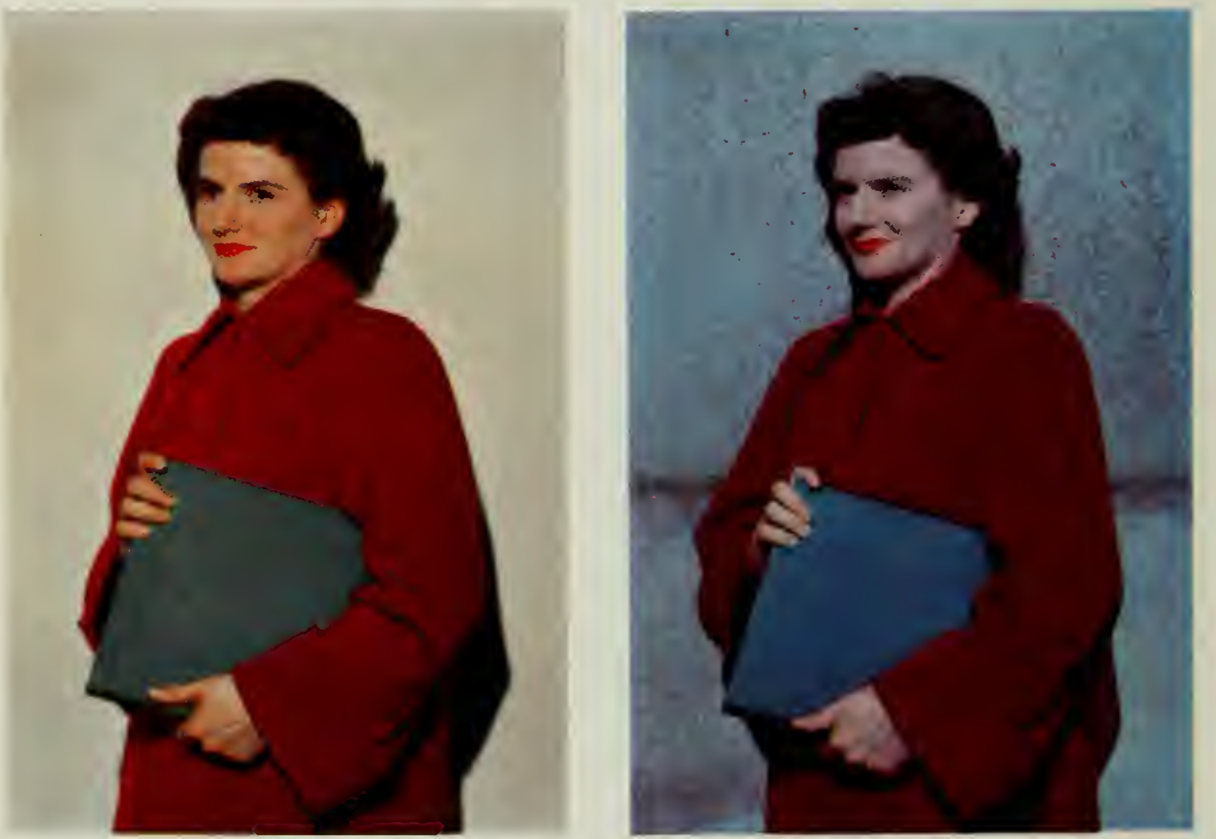
We have noted that 16mm Kodachrome Film and Ansco Professional Film are the only multilayer color camera original reversal films presently used in professional motion-picture work. Color release prints are made by numerous laboratories by printing the camera original onto another color reversal material such as Eastman Reversal Color Print Film or Ansco Color Duplicating Film. Occasionally such reversal color prints are also made by reduction printing from 35mm color release prints.

Another system, which has been used to some extent, is to enlarge the 16mm reversal color original onto a 35mm color negative material and make the release prints on a multilayer color positive film. In this manner, 35mm release prints can be made by contact printing and 16mm release prints can be made by reduction printing from the 35mm intermediate negative. Technicolor imbibition color release prints can be made from reversal color originals by making sepa-



Daylight Type film exposed in daylight.

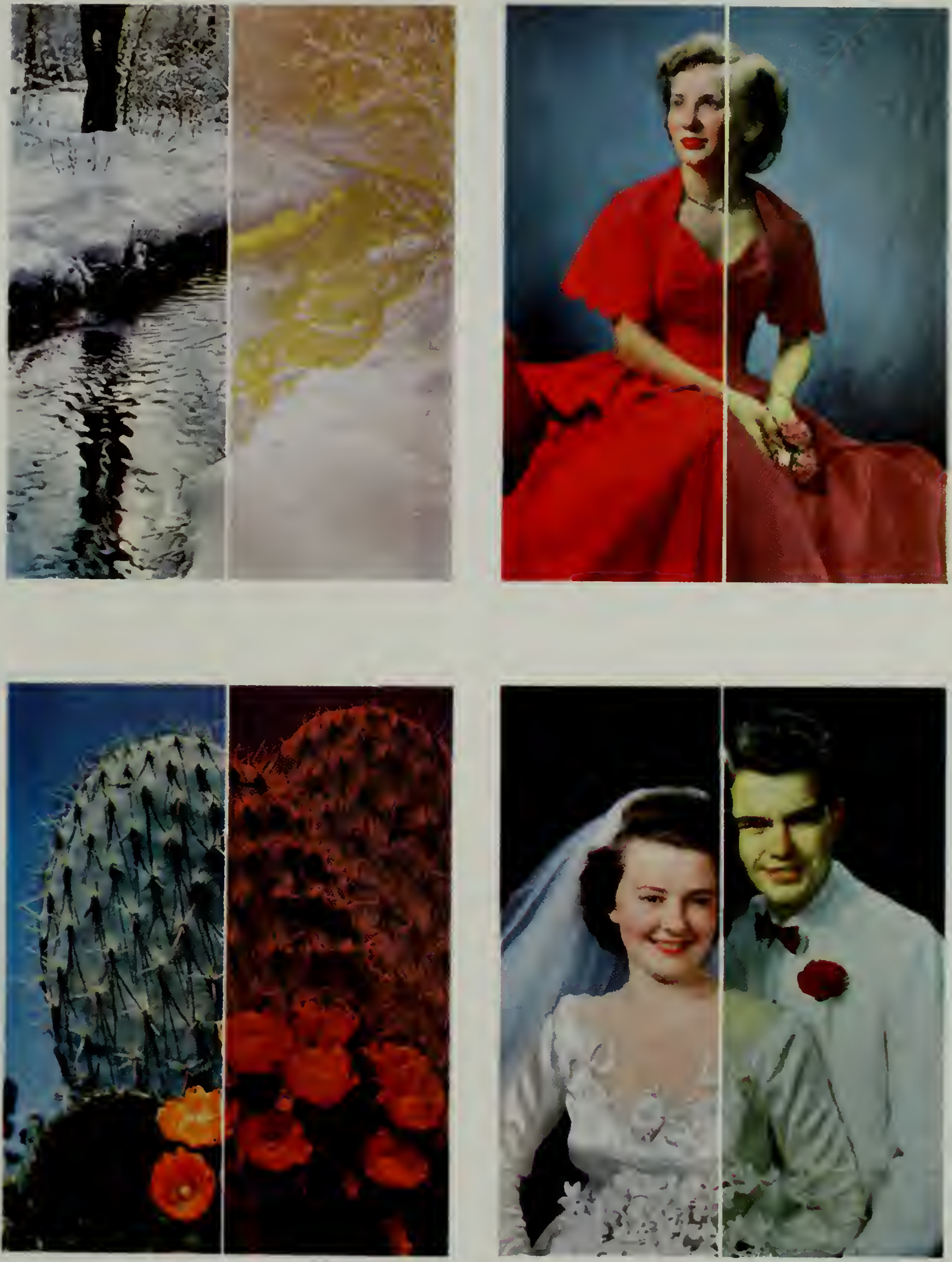
Daylight Type film exposed with 3200 K lamps.



Tungsten film exposed with 3200 K lamps.

Tungsten film exposed in daylight.

FIGURE 10: Effects of variations in lighting quality.
(Courtesy Eastman Kodak Company.)



Shown above are some of the more spectacular faults produced by incorrect processing. In each case, the lefthand side of the picture shows the result obtained with proper processing.

FIGURE 11: Effects of errors in processing color films.
(Courtesy Eastman Kodak Company.)

ration negatives and separation matrices, as was described for printing from 35mm monopack camera originals.

Where effects are to be included in the final release prints, three methods are available. In the first method, the reversal original may be edited as "A and B" rolls with alternate scenes separated by opaque leaders on each. By means of a special printer, the individual scenes are printed onto the reversal color duplicating stocks in alternate succession, incorporating the fades and dissolves as required. In the second method, second generation prints may be made from the first generation prints using the same reversal color duplicating stock. In the third method, the reversal color original is printed onto a color intermediate film. This color intermediate film contains the various effects desired. It is then contact printed onto a multilayer color positive film.

COLOR BALANCE

For a color process to reproduce colors approximately as the eye sees them, the responses of the camera original film to red, green and blue light must be in about the same proportion as are the responses of the eye to these additive primary colors. If the film has relatively too little sensitivity to red light, for example, or if the illumination used for photography is relatively too weak in the red wavelength region, the red constituents of all colors will be underemphasized. As a result, unless compensation can be made without adversely affecting the reproduction of the blue and green constituents, reds will reproduce dark and unsaturated; neutral grays will take on a cyan (blue-green) hue; and colors which contain red will reproduce too blue, too green or too cyan, depending upon whether such a color contains only blue, only green, or both blue and green constituents in addition to red.

Matching the color sensitivity of the eye would be simpler if the three receptor systems involved in human vision were unvarying in their responses to light. Unfortunately for the film manufacturers, this is not the case. As we already know, the eye adapts itself to the prevailing illumination, and in so doing the relative sensitivity of these receptors actually changes. For example, as we go from daylight into weaker and yellower tungsten light, the sensitivities of the red, green and blue receptors all increase; but the sensitivity to blue light increases to a much greater extent than the sensitivity to red, thus partially compensating for the lower portion of blue in tungsten light. On the other hand, if we go from *weak* daylight into *stronger* tungsten illumination, the sensitivities of all three receptors decrease, but the sensitivity to blue light decreases less than the sensitivity to red light, still compensating for the lower proportion of blue in tungsten light.

As we have seen, this type of adaptation is a great convenience in everyday life, reducing our consciousness of color variation resulting from changes in the color of the illumination, thus making the apparent colors of objects approximately constant. A color film, however, not having this built-in adapting mechanism to achieve color constancy, has only a certain, *fixed color balance* which is determined at the time of manufacture. Therefore the best possible reproduction of a scene can be obtained only when the illumination used to expose a film is of the particular color quality for which the film is balanced. For while the eye will adapt in order to see either daylight or tungsten light as white, a film which is balanced for daylight can only "see" tungsten light as yellowish, and a film balanced for tungsten light can only "see" daylight as bluish, as illustrated in Fig. 10. If a film balanced for light of a certain color quality is to be used with illumination of a different color balance, then the film must be exposed through a filter which will change the color quality of the light to the color quality for which the film is balanced.

Not only do daylight and various types of artificial light differ in color balance, but individually each is subject to considerable variation. For example, two extremes of illumination which occur simultaneously on a clear day are the reddish late afternoon sunlight and the bluish skylight found in the shade. If a scene contains objects both in the reddish sun and in the bluish shade, it is obvious that no filter can correct for both. A bluish filter which would correct for the excessively red sunlight would only make the objects in the shade appear still bluer. Likewise, a reddish filter which would correct for the excessively blue shadows can only make objects in the sunlight appear even redder.

In practical use, the color balance of a film may be affected by such factors as high temperature or high humidity during storage, before or after exposure. It can also be greatly affected by variations in processing. Figure 11 shows some of the more spectacular effects of incorrect processing of a multilayer color film.

5. Planning a Motion Picture in Color

Now that we have considered some color fundamentals and the currently important color films and processes, let us proceed to examine the use of color in professional motion pictures.

THE IMPORTANCE OF COLOR

Not many years ago when a producer began to plan the production of a motion picture he automatically thought of it in black-and-white. At any major studio, many vital conferences were held in the "front office" before a picture was made in color. There were good reasons for this. Raw stock, dailies, additional lighting on the sets, laboratory work, print costs — these and other items made a picture cost considerably more in color, and a producer must always be thinking about recouping the huge investment required by a major motion picture.

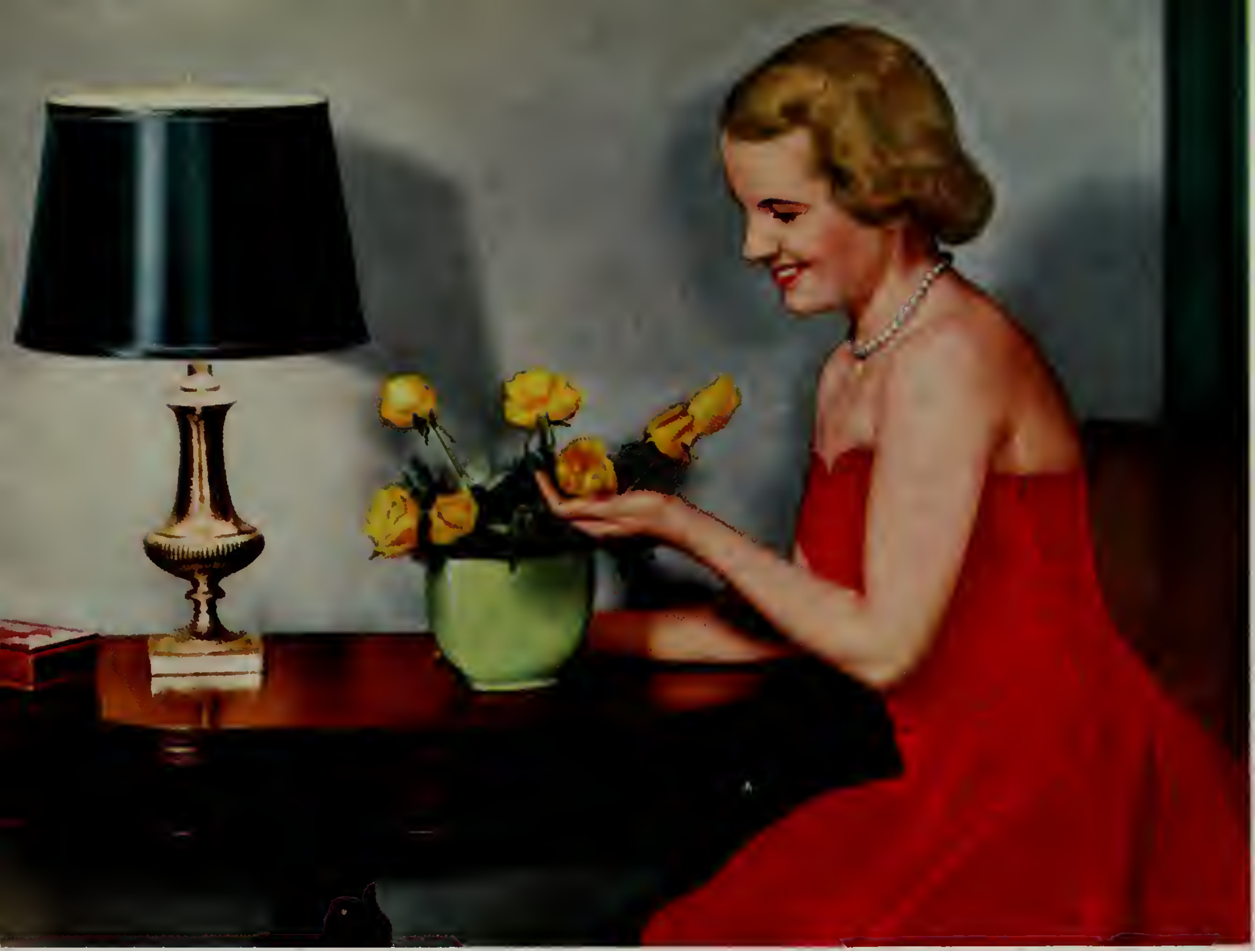
Today, however, the situation is exactly reversed. Producers have come to accept color in motion pictures as a matter of fact. Now the production of a picture is automatically planned in color, and vital "front office" conferences are held before a picture is made in black-and-white, even though there is still a larger expenditure of money involved in the use of color. The simple fact of the matter is that color has proved to be a tremendous asset to a motion picture — so much so that it has often been considered another "star" in a picture, included in the advertising, in the publicity, and usually on the marquee.

Currently about two-thirds of all the motion-picture entertainment produced annually for theatrical release is in color. The amount of color used in television is much less, of course; but a surprising amount of original photography for television is presently being done on multilayer color camera negative, or color reversal film from which black-and-white prints are made for immediate distribution. The color original is then stored away for future use.

There are those who believe that color will eventually replace black-and-white, both for theatrical and for TV entertainment. And there are those who believe that black-and-white motion pictures will always be with us. There seems to be no one, however, who does not agree that for the most part the motion-picture entertainment of the future will be in color.

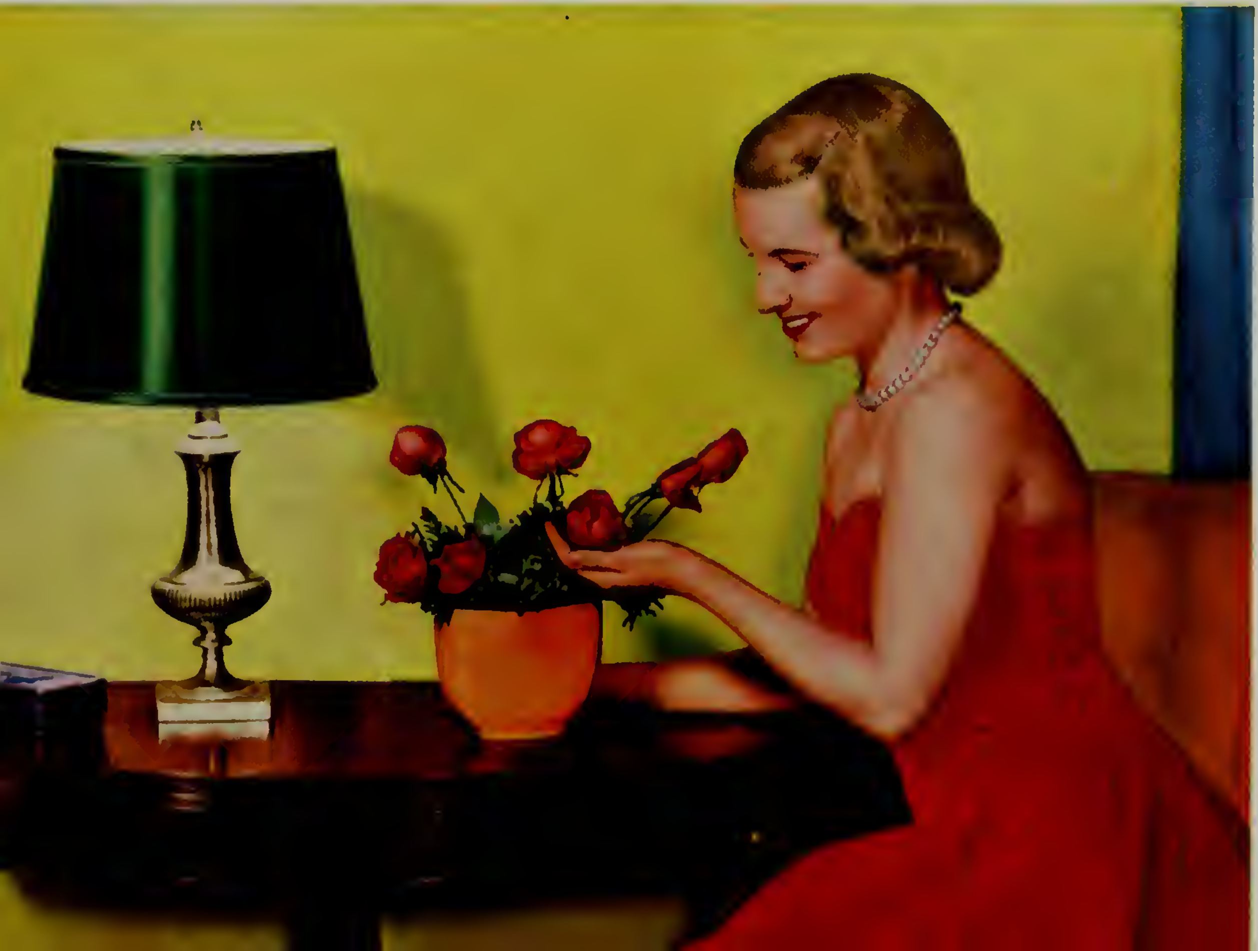
COLOR HARMONY

Color harmony may be defined as the systematic arrangement of colors to give a pleasing effect. The subject of color harmony is complex, and to a certain extent a matter of personal taste; nevertheless there are certain fundamental principles which apply.



(Above) A pleasing arrangement of colors. This is only one of the many good combinations possible. (Below) An extreme example of poor color harmony. Note how the distracting colors of the surroundings draw attention away from the principal subject of the picture.

FIGURE 12 (Courtesy Eastman Kodak Company.)



Most outdoor scenes display good color harmony, probably because our minds have grown to accept the color combinations of nature as pleasing. Indoors, the colors of background, clothing and other elements of a scene can be controlled, and therein lies a danger — the fact that it is easy for us to become obsessed with the wide gamut of colors we have at our disposal. We might well take a cue from nature, and recognize that the most pleasing color pictures are generally those in which only a limited range of colors is used. Likewise, the use of relatively unsaturated colors will frequently add to the naturalness of a color picture.

Examine carefully the pictures shown in Fig. 12. Both are the same in every respect except color, and so provide a valid comparison of color schemes without variations in other factors such as subject, pose and lighting. The top picture is a pleasing arrangement of colors, while the bottom picture is an extreme example of poor color harmony. These pictures also show how a warm colored background tends to appear nearer than a cool colored one, thereby decreasing the apparent depth of the scene.

The effect of a given color scheme depends not only upon the colors themselves, but also upon their comparative areas and their distribution throughout the scene — that is, their juxtaposition. In general, large areas of harsh, brilliant color are seldom pleasing, and are best avoided unless included to serve some unusual purpose. More dramatic effects can be obtained by surrounding a subject with complementary color, whereas small touches of related colors will soften the severity of bolder contrasts. Textures of colored surfaces are also important because they can lead to different color rendition under various lighting arrangements.

OVERALL COLOR PLANNING

A color motion picture as a whole, as well as its succession of sequences, must be conceived not only in color harmony but also in the proper color key. A western, for example, plays well if we merely add generous quantities of red to the natural coloring of the outdoors. Warm, neutral colors contribute to the homely reality of an historical classic. A musical or a pageant calls for a broad gamut of saturated, emphatic colors. A comedy is usually conceived in an effect of bright backgrounds with sharp color accents. And so on. Moreover, within a picture it becomes desirable to use different effects in different sequences, so that the story changes in locale and mood are attended by appropriate color changes.

The overall color planning of a motion picture may originate at any of several sources. The producer or the director may have a flair for thinking in color terms, and thus be able to outline the color effects from the start. In other cases, the art director and the color coordinator, and sometimes a special designer, may be given this important creative work to do. Frequently it is the combined thinking of a number of people, under the art director's guidance, which sets up the color program. This program is then crystallized in the form of color sketches of sets, locations and wardrobe for general approval and guidance.

There are many factors which strongly influence the overall planning of a color motion picture. The feminine star, for example, whose appearance is of paramount concern, must be given undisputed priority as to the color of make-up, hair and costumes which will best compliment her complexion and her figure. If her complexion limits the colors she can wear successfully, this in turn restricts the background colors which will compliment her complexion and her costumes to best advantage.

Fixed colors, such as sky, foliage, skin tones or exterior locations which have predominant background colors will be encountered. These fixed colors become determining factors in selecting colors for wardrobe, sets and properties.

No rigid decisions about color compositions can be made until all considerations such as those above have been weighed. Specialized artistic contributions come from all departments and are integrated into a master color plan. This plan is then detailed and carried out by departments, the objective being to have color "act" with the story, never being a separate entity to compete with or to detract from the dramatic content of the picture.

ART DIRECTION

The great artists have consistently used color to enhance their compositions, to focus attention, and to accentuate rhythm. Motion pictures (and live TV as well) can combine all of these functions of color with an additional, dynamic quality — that of *color in motion.*

In a motion picture the composition is never static. People move, lips move, the camera moves, the point of view moves. And color moves — not only within a scene, but, through "cutting," there is color motion in the juxtaposition and succession of scenes. The interesting speck of color in a long shot can, in one cut, become the screen-filling color in the following close shot. This degree of versatility, which makes possible the telling effects achieved when color is used with skill, is the very reason why color, if uncontrolled, can work to the detriment of a picture. As we have noted, color in a motion picture must help tell the story. If it does not do this we invariably find it in competition with the story.

Generally speaking, the specific problem with respect to the use of color in a motion picture set is to use fewer hues and to use colors of lower saturation, especially for background colors. We are familiar with the manner in which a clutter of detail in the background of a black-and-white picture will cause our eyes to wander away from important foreground action. A background which is a clutter of color will do the same. And if a background is a clutter of *color and detail,* it becomes an even stronger visual magnet. By using fewer and less saturated colors as well as by simplifying background detail, any action of the actors becomes more definite and emphatic, and color plays its proper role as one of the prime factors of story-telling. Surprisingly enough, perhaps, the use of unsaturated colors does not result in a drab or grayed version of reality, but appears as reality itself. Here, again, we must consider the difference between what the color film can see, and what the human eye can see. What we see on the screen when we reduce the number and the degree of saturation of the colors on a set is what we believe we see in everyday life.

This psychological factor can be one of great importance in creating an atmosphere of reality or verisimilitude on the screen. With the filming of an historical or a "period" picture, for example, research is done not only on architecture and decoration, but also on the colors in use during the particular period and in the specific country. Yet the use of the actual colors of the period or the country are very rarely employed. Because of psychological factors governing the response of a modern viewing audience, far better results are achieved by the use of a *desaturated tonality of the times* — that is, a less saturated range or "palette" of color and pattern, but adequately punctuated with authentic identifying colors so that the end result tends to be identified as historically accurate, yet believable. If, during a particular historical period, a great artist or a great school of art existed, a limited palette will sometimes be developed from these paintings and used as the general color theme of the picture. One recent motion picture was done with the paintings of Rembrandt as a basis, modified of course to suit the psychological responses of a modern viewing audience.

Modern and documentary pictures, a good part of which are often filmed in the studio, present a different color problem. To be believable, and in most cases to tie in with actual scenes filmed on locations, *identifying colors* are necessary to give realism. Actual color "stills" are usually studied for attention-attracting or identifying colors, and the use of these identifying colors will then easily create an atmosphere of authenticity and bridge the cuts from real to studio settings. In street scenes the identifying color might be the particular hue of a building or a sign. For interiors, the identifying color is one that relates the interior to the actual exterior shot on location. And if the interior set is a copy of a well-known locale, then the general tonality of the actual room must of course be used.

Particular attention must be given to the color of foliage, especially when natural exteriors are intercut with exteriors filmed on a stage. There are many hues of green foliage, ranging from yellow greens to very blue greens. If the hue of the natural foliage is not faithfully reproduced on the stage, the difference will disturb the viewing audience. We may not realize exactly what is disturbing us as we watch the picture, but the disturbance will be there, distracting our attention from the story, at least momentarily. This is just another example of color working against us if we do not take the trouble to make it work for us.

Musicals and fantasy pictures are open to unlimited opportunities in the use of creative color. Here we are not held down by reality, past or present, and our imaginations can soar. Musicals and fantasies are usually designed to provide the eye with visual pleasure in the way that music pleases the ear. Many times the central color theme is indicated by the story, by the music, or even by lyrics or verses involved. During the past few years much use has been made of the modern master painters for ideas — Picasso, Toulouse-Lautrec, Braque, Utrillo, Modigliani, Rousseau and others. Of course, a picture of this type necessitates a tight control of color by all departments, in order that the desired moods and effects do not get out of hand.

The mood to be employed in the filming of a motion picture is often of importance in planning the color. A picture with many low-key or night exterior scenes usually requires that dark colors be increased in brightness, and sometimes in saturation, to keep them from reproducing as black or near-black. Conversely, a picture with many high-key scenes will require that light colors be decreased in brightness, and sometimes increased in saturation, to keep pastel shades from "washing out" to white or near-white. These adjustments are necessary because no color film (nor even the fastest black-and-white film) can be made to cover a brightness range even approximating that of the human eye.

Our vision, with its remarkable ability to operate over a tremendous range of operating levels, can perceive color and detail both in dark-colored areas at low levels of illumination, and in light-colored areas at high levels of illumination. Film, lacking the adaptive mechanisms of the eye, simply cannot "see" over this wide range of light levels. For this same reason, it has become general color motion-picture practice to use an "off-white" rather than a true white, and a "navy" or a "charcoal" rather than a true black. These colors photograph white and black, respectively, and yet retain modeling and detail.

COSTUME DESIGN AND WARDROBE

As we have already seen, color from the point of view of the costume designer and the wardrobe supervisor is never an isolated problem. Color problems related to costumes are part of the master color plan which is worked out with the Producer, the Director, the Art Director, the Director of Photography and the Color Coordinator — before any preliminary work is started or any discussions are held with stars or players.

In designing costumes and selecting wardrobe, as we would expect, the same color principles apply as we found applying to art direction. Color must be subordinate to the story, and help to tell it. The colors in costumes cannot be permitted to become "eye-catchers" unless such an effect is deliberately desired, and so helps rather than hinders the story.

We have seen that sets and locations establish locale, mood, time and circumstance of the background. Costumes and wardrobe do the same, but have the added function of punctuating the actor against the background. Consequently the color of the costumes usually is slightly complementary to the background, or slightly more saturated, and so helps us to center our attention on the actors and follow the story. In most cases, two specific situations occur: many characters work against a particular background; and one or more characters wear the same costumes throughout several scenes, thereby working the same costumes against several backgrounds. Particular attention is required, therefore, to insure proper separation between wardrobe and backgrounds throughout the picture.

We saw how identifying colors are used to relate sets to actual locales. both exterior and interior. Costumes can also function in this way. For example, the particular colors of a hotel doorman's costume might serve as a color connecting link between interior and exterior scenes. Too, just as the colors used in historical sets are "modernized," so are the colors of historical costumes subtly changed, so that the end result can be identified as historically accurate, yet believable.

As we have seen, skin tones are of prime importance in a color picture. Specific attention is given, therefore, not only to the relationship between skin tones and background, but also between skin tones and costumes. For example, if make-up color is changed to denote the different races of people, other colors should be altered accordingly. As make-up becomes darker, the costumes should employ deeper and more saturated hues. Whites (off-whites) next to skin tones should be dropped somewhat in value, and any large, light areas are also best decreased in value. If a dark make-up is used, an actor wearing a "white" blouse or shirt will appear considerably darker than when wearing a shirt or blouse of lower value — say, a medium gray. If we ignore this fact we will find that either the complexion color or the costume color seems to change from scene to scene, depending upon how the scene is printed.

Color "normalcy" is generally the goal when wardrobe is selected for a color motion picture. By color normalcy we mean that we do not try to *force* color into a picture just because we happen to be working with color. For example, if an actress in a given story situation would likely appear in a gray dress, she is not put into cerise just because it is more colorful. This principle holds even if the color key of the picture is light and gay. Naturally, as stated earlier, color normalcy does not apply to musical or fantasy pictures, where color is unrestricted by realism.

Experience has shown that there is a great deal of validity to the psychology of color, at least as far as color costumes are concerned, and an actress is never forced to wear a certain color if it can be avoided. Years ago an actress would have been considered temperamental if she balked at wearing certain colors; now we realize that color preferences and dislikes are quite normal, and to respect them often helps an actress to portray a role better.

Another color "don't" is to "give away" the dramatic content of a scene which is just beginning to be played. For example, we often avoid black and somber colors for sad scenes if we do not want the audience to know in advance that the scene will be sad. Gay colors for gay scenes are often avoided for the same reason. This is just one more way of controlling color so that it helps to tell the story as effectively as possible.

COLOR COORDINATION

The fact that color in a motion picture is selected piecemeal, by many people and over a period of many days, explains why a color coordinator is desirable to maintain order—the order of good color composition. A color coordinator has two main functions: he insures that the subject matter to be photographed will appear to have the right colors under final viewing conditions; and he takes up artistic slack in carrying out the color master plan for a motion picture.

Color coordinators were first introduced to the motion-picture industry by the Technicolor Corporation. At that time, Technicolor was the only commercially successful color process in the professional motion-picture field, and what few pictures were made in color were in Technicolor. Consequently, the industry's color problems became Technicolor's problems, and not the least of these was the problem of color control, which could not be restricted to the laboratory, but had to be extended to the studios and incorporated into the planning and production of a picture. So Technicolor set up a "color consulting" department. Its members worked closely with the producing companies and with the Technicolor laboratory. They worked to secure quality color pictures on the screen, and to avoid costly errors, particularly in the preparation stages of a motion picture.

Of necessity, a color consultant had to see all the material that was being prepared — sets, costumes, backings, furnishings, all the items that appear in the picture. Consequently he knew as much about the color details as anyone connected with the production. It followed, then, that it was expedient for the producing company to have him as a "color coordinator" among the various departments. This was a logical step, for a color consultant had a background of experience in the artistic use of color, plus a knowledge of the laboratory methods of processing color film.

The studios producing black-and-white pictures had no comparable department. Black-and-white pictures posed no problems concerning hue or saturation; there were only brightness values to consider, and the ease with which these brightness values could be coordinated left the separate departments within a studio quite independent.

It may well be that the presence of an outsider, with no intramural attachments, succeeded in initiating the habit of color coordination in the smoothest way possible. The Director of Photography, the Art Director, the Costume Designer and the Make-up Artist all welcome the Color Coordinator as an appreciative collaborator to control the interplay of color among complexions, costumes and backgrounds, so that the special artistry of each will not be negated in the final color reproduction by false notes creeping in as a result of a lack of complete execution of the color master plan.

The Director of Photography, of course, is the final artist who composes the set-ups. His choice of lens, angle of view and lighting technique gives him a high degree of flexibility for artistic presentation. However, while the Director of Photography is a party to formulating the color master plan for a picture, he is seldom able to concern himself with color details, most of which are worked out long before the date of photography by numerous specialized artists and craftsmen who prepare the sets, costumes, furnishings, properties and backings to be used.

In one sense, then, the Color Coordinator is the righthand man of the Director of Photography during the preparation period — foreseeing the compositions which will be needed; insuring colors and textures that will provide balance in each set-up; adjusting backgrounds to make-up, so that dynamic portraits can be rendered and special depth portrayed; and determining contrasts of light and dark colors which the Director of Photography can keep under control without the costly and time-consuming necessity for individual lighting on different areas.

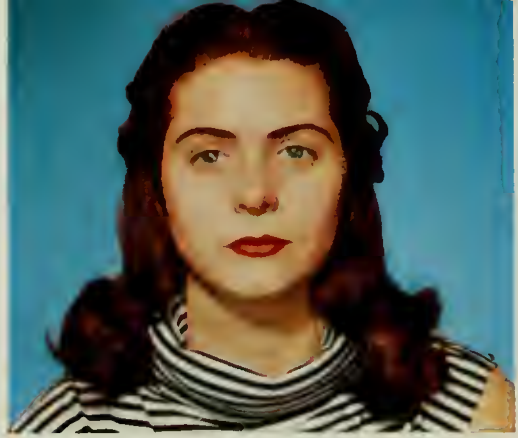
The Color Coordinator is certainly a righthand man for the Art Director. He is equipped with large files of color samples for quick reference, and he retains swatches of wardrobe so that color selections for the sets can be made to exact references. He brings to the Art Director the information needed to make decisions, and he helps spark creative thinking, just as he does for wardrobe, make-up, set decorating, scenic and other departments.

The final requirements for every choice of color are imposed by the color reproducing medium — the color film and process to be used, and whether the final prints are to be made for theatrical or for television presentation. There are some color distortions in all color reproducing media, and the magnitude of these distortions, if ignored, is often great enough to spoil a good color design, the impression of realism, or the appearance of a star. If the artistic intentions of a picture's color master plan are to survive, therefore, these distortions should be compensated for at the time each item of color is selected. The Color Coordinator, being laboratory trained, can visualize color in final viewing terms. He takes the responsibility of applying compensations which he knows will deliver to the ultimate viewing audience the colors which were intended.

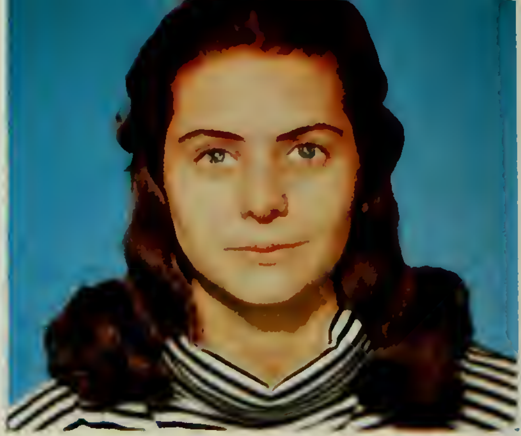
The growing practice of having the Color Coordinator sit in with the laboratory group when they "time" the prints, and also with the producing group when the prints are viewed, completes the circle of control. Benefits accrue both ways from this — the producer, director, cinematographer and editor have a direct agent to secure from the laboratory the results they want; the laboratory has all the information needed to deliver those results promptly and economically.

MAKE-UP

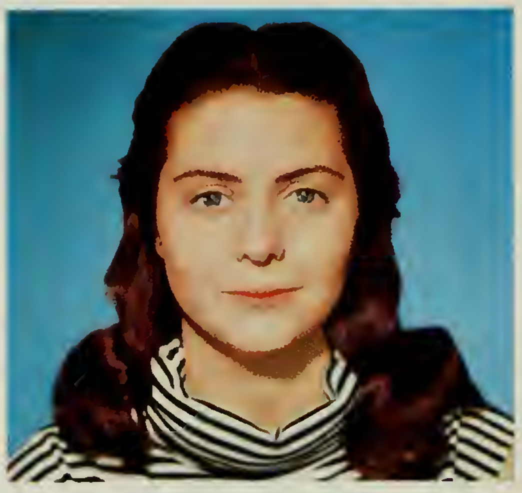
Make-up is essentially a "production" problem — that is, except for prepro



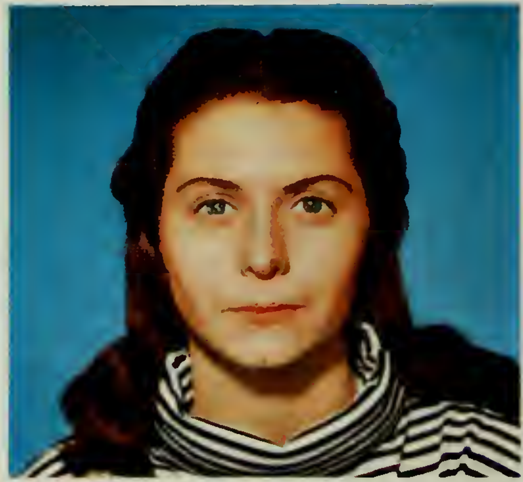
A usual, incorrectly applied make-up.



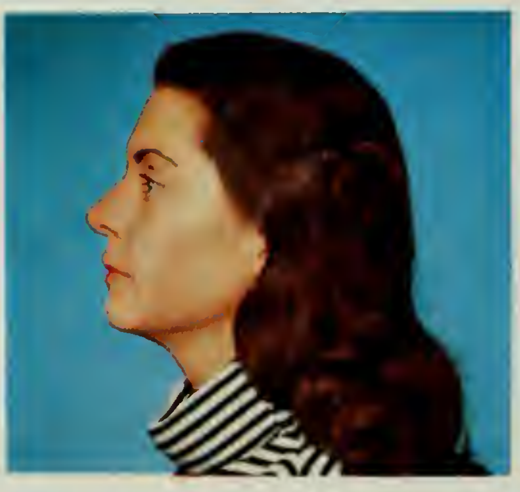
Same model, all cosmetics removed.



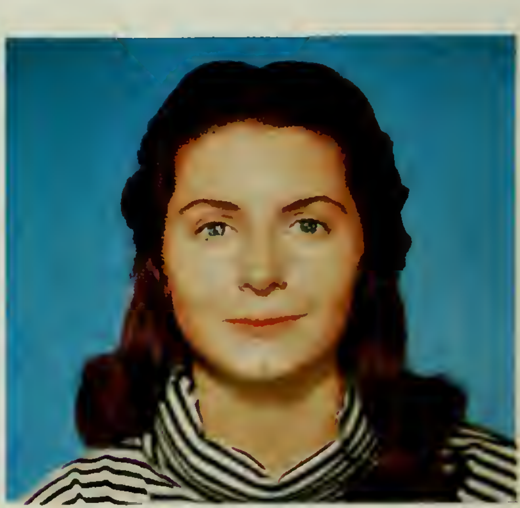
Correct application of proper foundation color.



Application of shadow color to minimize width of jaw and side of nostril. A painted cleft in the chin helps to elongate the face. No blending at edges yet, to clearly illustrate the line of application.

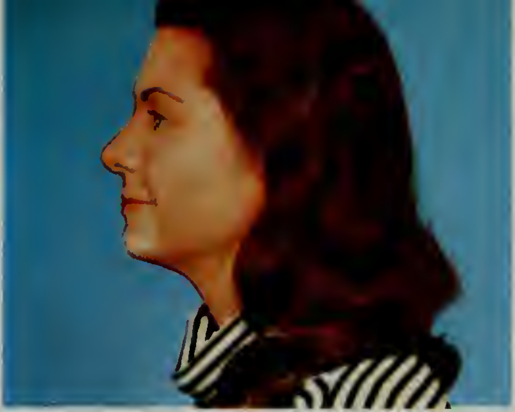


Profile view of shadow color application.

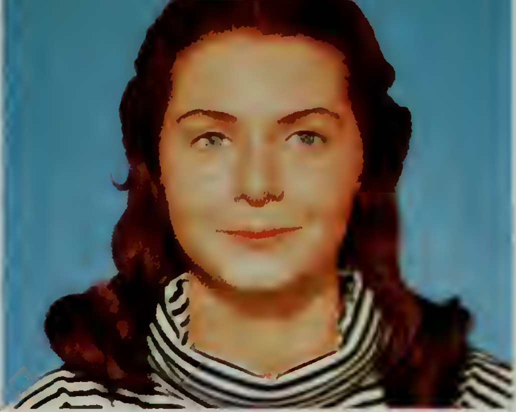


Correct application of highlight color under the eyes to erase circles, at corners of nose to erase lines, and on either side of the cleft in the chin to further emphasize length of face. Edges of shadows have been blended, but not the highlight application.

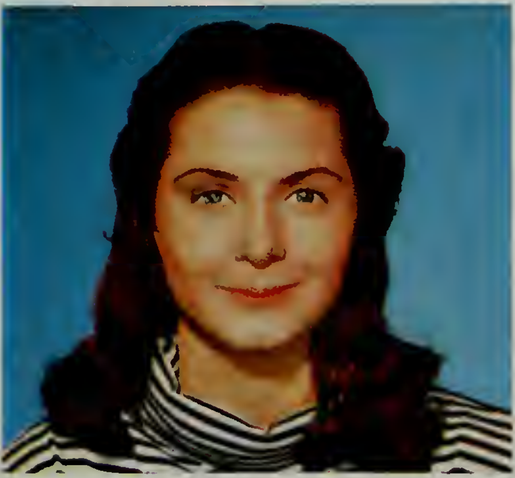
FIGURE 13



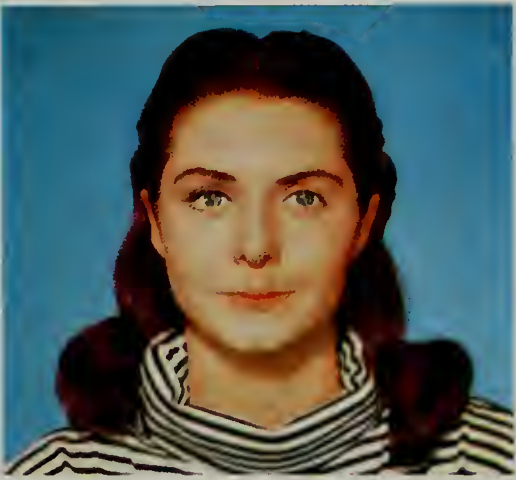
Profile view of highlight color application.



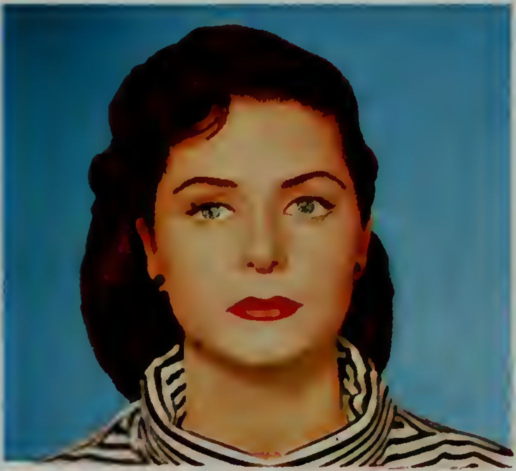
Correct application of cheek rouge. Edges of highlight color have been blended, and rouge is applied diagonally to cheek bones, just above the line of shadow application.



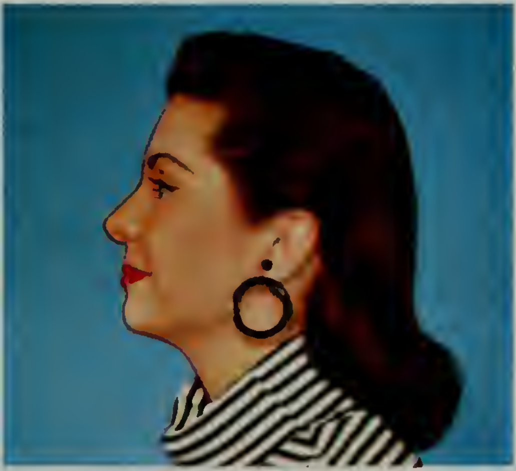
Initial application of eye shadow color.



One eye completely made up, with eye shadow blended. Correct contour and density of brows with eyebrow pencil. Correct application of mascara to eyelashes. Compare with the model's left eye, which has not been made up.



Completed make-up. Powder has been applied, lips properly shaped with correct hue and value of lip rouge. Hair changed to compliment the facial contours.



Profile view of completed make-up.

(Make-up by William Tuttle; Color Photography by Clarence S. Bull; Courtesy Metro-Goldwyn-Mayer Pictures.)

duction tests, it must be dealt with primarily during photography. But as we have seen, the make-up for a color picture must be included in the color master plan. Make-up must be considered in advance with respect to the stars and featured players to be photographed, for, since the object of color make-up is to enhance the natural complexion tones and contours of both men and women, the make-ups for different actors must be different.

Make-up must also be considered with respect to the particular color films and processes to be used, because make-ups for the same actor will differ with color processes. Even the color balance and intensity of illumination used for photography must be considered, for these factors can directly affect the colors of the make-up. And finally, as we have seen, the make-up colors must be integrated and coordinated with the other color ingredients, especially the costumes and the sets.

Color make-up problems differ from those involving costumes and sets in several respects. The variety of pigments that can be used in cosmetics is limited to those approved by the Pure Food and Drug Act. And, make-up normally cannot cover the surface of the skin the way paint covers a wall. Foundation make-up can never be applied so heavily as to completely conceal the texture of the normal skin. A heavy application results in a mask-like appearance, whereas an important aspect of make-up for color cinematography is the production of a "natural" complexion tone for both men and women.

Special make-up foundation colors are made for each color process, but merely using the correct series of colors for a particular film is not enough. Selecting the proper shade (the proper combination of brightness and saturation) for each individual actor or actress is the secret to obtaining the most natural results.

Let us try to define exactly what is meant by a "natural" make-up. Paradoxically, it is *not* an exact reproduction of a person's natural skin tones. Actual color measurements made on the faces of both men and women show them to be considerably redder than we would accept in a color reproduction. On film, we want complexion tones to appear more pink than they are in real life, and it is this overly-pink skin tone which our vision tells us is natural. This has been recognized for many years on the legitimate stage, where spotlight filters aptly named "illusion pink" are used to glamorize the female complexion. If we actually do reproduce a beautiful woman's complexion exactly as it is in real life, we will consider it "too ruddy" or "unnaturally reddish," and so will she.

Not only do complexion tones have to be reproduced more pink than they really are, but, as we have already indicated, they must also be the optimum shade for a particular actor or actress. Variations in shade may be required to bring out the very subtle pastel hues so necessary to a good skin tone, or they may be necessary for corrective purposes. For example, if a woman has an unusually ruddy complexion, a darker shade of the proper color series will be required than if her complexion is more normal. In this instance the darker make-up helps to conceal the ruddy tone of her skin, and at the same time it prevents her skin tone from becoming too light.

As a rule, the most flattering skin tone for a woman is one which gives sufficient contrast between her skin and her eyes, so that the eyes, usually considered the most expressive element of the face, become the most important feature by virtue of color contrast. There are some occasions, however, when, because of the type of character being portrayed, the make-up for an actress (or an actor) must be lighter or darker than the same actor would require for a "straight" type of role.

The fact that corrections of various sorts have to be made on many faces necessitates that a substantial range of shades be available in every make-up color series. Areas that are too prominent can be subdued by using a foundation color about three shades darker than the base make-up color. Or, a foundation color about two shades lighter than the base color is often used to highlight areas of a face that would otherwise recede undesirably, such as dark circles under the eyes, or lines at the corner of the nose. This same technique of highlighting and shadowing is also necessary in producing certain character effects, or in simulating the appearance of greater age, by emphasizing lines and wrinkles in the face with shadows, and by highlighting certain fullnesses such as jowls or cheek bones. These techniques have been used in black-and-white motion pictures for many years. They are more difficult with color, but considerably more dramatic when properly done.

Sometimes actors and actresses are photographed with little or no make-up. This is not because their skin tones will reproduce perfectly on color film without it; it is rather that they are playing "extra" roles, and never get close enough to the camera for make-up to be important. Actresses playing "atmosphere" type parts are usually made up with the customary light foundation colors used by women for ordinary street wear. Men playing similar parts are usually not made up at all. People playing "bit" parts, however, who may be photographed in a close shot with one of the principal players, may have to be made up as carefully as the stars.

It is always necessary to consider carefully the foundation make-up with respect to the color balance between men and women. If a woman's make-up is very light and a man's is very dark, the variance in complexion tones will be so obvious on film that it will appear unnatural and disconcerting. Selection of foundation colors which are closer together in value will produce a better balance and give a more pleasing picture. Even though this may be somewhat of a compromise for each of the actors in question, it will usually result in a more natural appearance for both when they are photographed together.

The technique of applying make-up is fully as important as the proper selection of colors, if the perfect effect we are seeking is to be achieved. As we saw earlier, make-up should never be applied too heavily. Highlights and shadows to correct facial proportions must be blended very delicately, so that each color fades naturally into the foundation color. Cheek rouge should be a pastel, blended to a soft blush tone. Eyebrows should be penciled with tiny hair-like strokes to simulate real hairs, never drawn in a solid, continuous line. Make-up should always be applied to the neck, shoulders and arms, if exposed, so as to achieve a continuity of color tone from a woman's hairline to the neckline of her dress. Lip rouge is best applied with a lip brush, so that a perfectly sharp line is achieved. Figure 13 shows several steps in the production of a good make-up.

In producing red lips, we are confronted with a situation which is somewhat unique. The lips are extremely small in area, and they are always surrounded by an area which is lighter in color — namely, the flesh tones of the face. Too, there is only an extremely small portion of the lips that ever falls in the highlight region of the film, this tiny area being the fullest point of the lower lip. The lip rouge, consequently, must be selected with great care or the lips tend to reproduce dark and opaque. In general, the darker the lip rouge the more degraded and opaque the lip color becomes on film. This has ruined many an otherwise good make-up, causing an actress to appear "hard" and "made-up."

For color, most make-up artists prefer to use an oil base foundation rather than the pancake, or water soluble, type of cosmetic. An oil-base foundation can be applied thinner in most cases, and the degree of oiliness which comes through after powdering gives the skin a very natural sheen which is difficult to obtain with a water-soluble base. Pancake-type make-up is widely used for body make-up, however, in colors to match the oil-base foundation used on the face.

Space does not permit us to list here the various color series of cosmetics designed especially for the various color films and processes. Make-up charts for Ansco Color, Eastman Color, Technicolor, and even live color TV are available from the various cosmetics manufacturers.

6. Photographing a Motion Picture in Color

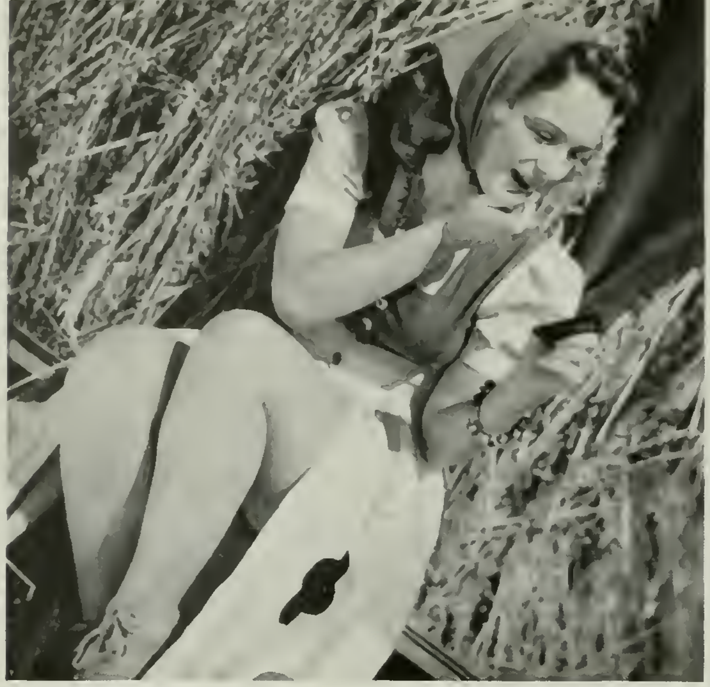
"Production" — the actual filming of a motion picture — is the phase toward which all the preproduction planning, working and coordinating have been directed. All the actors and materials are assembled, the Director breathes life into them, and the Color Cinematographer becomes the final artist who transfers them to film. It has been said that a cinematographer's task is to record the original objects as realistically as possible, but this does not go nearly far enough. He must make them appear *more* real than the originals, just as the events in a successful motion picture must seem to be more real than similar events in everyday life.

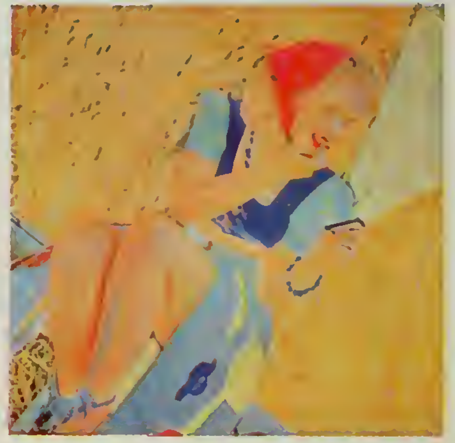
COLOR COMPARED TO BLACK-AND-WHITE

Since we live in a world of color, it is only natural that, in general, we should find color pictures more realistic than black-and-white pictures. Comparatively speaking, black-and-white photographs are more of an abstraction from reality — more commonly accepted on their merits as *pictures.* A portrait, of course, is judged on likeness; but other types of black-and-white pictures tend to be judged without reference to, or without regard for the appearance of, the original scene. As a result, tone rendition can vary over a wide range and still remain satisfactory.

When we look at a photograph in color, however, we tend to make a more direct comparison between the subject and the reproduction. Our approval will be based to a considerably greater extent on our recollection of the original scene, or *our conception of how the original scene should have appeared.* If color photography is to be satisfactory, skin tones and such objects as have a definite appearance in our minds must be reproduced with what we believe to be reasonable accuracy, both in terms of tone rendering and in terms of color rendering. As we have seen before, color adds a new dimension, so to speak, to the mere representation of a scene in tones of gray, but it requires more control because of the greater variety of effects made possible.

We use the term "dimension" in a figurative sense here, but to a considerable extent it may be applied literally, for it is a matter of common observation that photography in color seems more three-dimensional than black-and-white. The illustrations of Fig. 14 demonstrate this very well. Here brightness differences can be seen to be more important than color differences alone in contributing an effect of depth to a picture; but the greatest perception of depth is unmistakably given by the color picture, in which variations in both color and brightness occur.

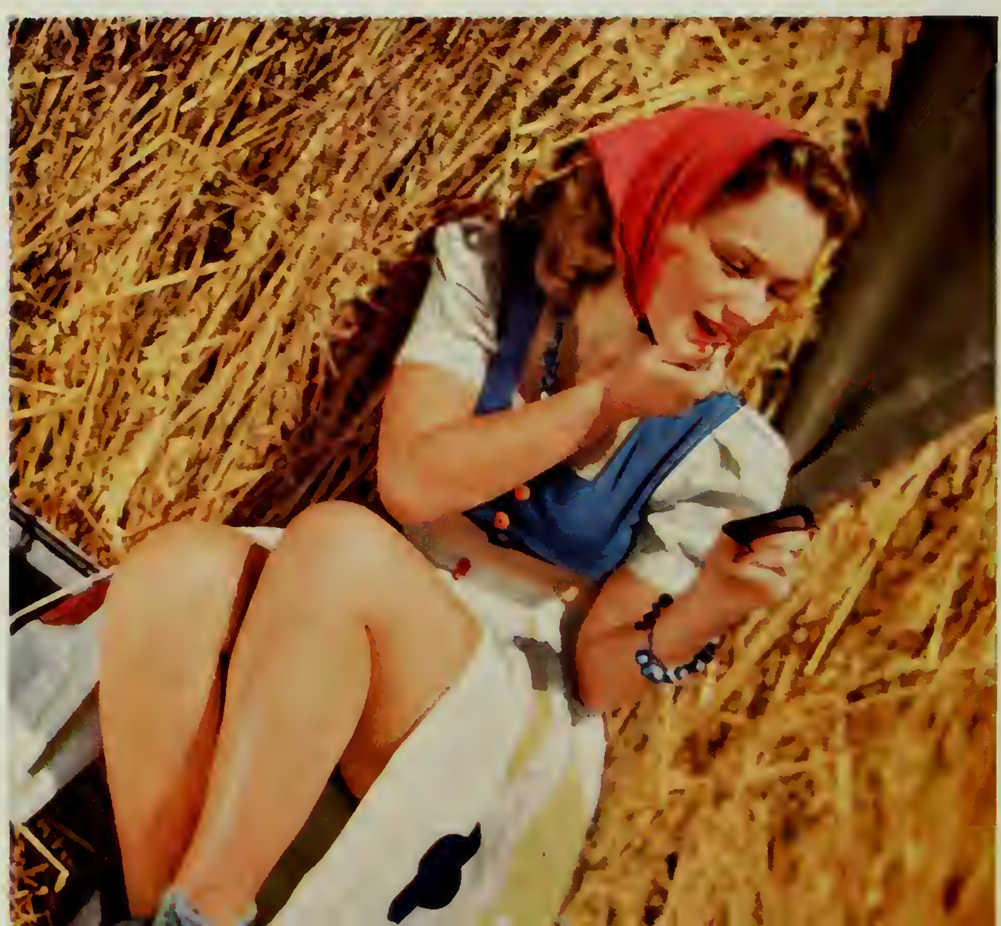




The illustration at the left, above, shows a normal black-and-white print prepared from a color transparency. At the right is shown a color print of the same subject in which the brightness differences among the colored areas have been greatly reduced. Comparison of the two illustrations shows that the perception of depth given by variations in brightness alone (left) is greater than that given by variations in color with the brightness differences decreased (right). Comparison of the illustration below with the other two shows that the greatest perception of depth, and by far the best picture, is given by variations in both color and brightness.

FIGURE 14

(Courtesy Eastman Kodak Company; reprinted with permission from Ralph M. Evans's *An Introduction to Color*, 1948, John Wiley & Sons, Inc.)



COLOR TEMPERATURE

The color quality of the light source, though only of minor concern in black-and-white photography, is extremely important when we photograph in color. As we have noted, a color film is without ability to adapt itself in any manner or degree, and so cannot "see" colors the way our eyes see them *unless the color quality of the illumination is the same as that for which the film is balanced.*

This necessity for illuminating a scene with light of the color quality for which a film is balanced means that, *except when special effects are desired, light sources which are appreciably different in color quality cannot be mixed.* Otherwise, extremely unnatural effects will be obtained, such as having a person's skin tone reproduced differently in color on one side of his face compared with the other. It also means that we need somehow to be able to define the color quality of a light source.

For *visual* purposes, the *color temperature* of a light source has been used to define its color quality, and this concept of color temperature has been applied to color photography. Color temperature refers to the color of a theoretically perfect source of radiant energy which emits light because of its very high temperature. Such a perfect thermal radiator — called "perfect" because it emits the maximum possible amount of light for any given source temperature — is known as a "blackbody" * radiator. The light it emits depends upon its temperature. The higher the temperature, the bluer the light; the lower the temperature, the redder the light. Now the color of the light emitted by most thermal radiators (or even by many sources of light which are not hot, as we shall see) can be matched visually by light from a blackbody at some temperature, and the temperature to which a blackbody must be heated in order to emit light of the same visual color quality is said to be the *color temperature* of the source in question. This temperature is expressed in degrees Kelvin (K), obtained by adding 273 to the temperature in degrees centigrade. Thus, when a light source matches *visually* the color of a blackbody radiator it is said to have a color temperature equal to the actual temperature of the blackbody in degrees Kelvin.

A simple example may help to clarify this concept of color temperature. Suppose we heat an iron poker in an extremely hot flame, such as an oxyacetylene torch. Iron is not a perfect blackbody radiator; however, let us *assume* that it is. As we hold the poker in the flame, the iron begins to get hot. Soon it is so hot that we would be painfully burned if we would touch it. It is not yet hot enough to give off light, however. But before long it does begin to glow a dark red. It is now "red hot," and its temperature is about 1000 K. And, since we are assuming it to be a blackbody, its color temperature is also 1000 K. Now any light source, *regardless of its actual temperature,* which gives off light of this particular red color would be said to have a *color temperature* of 1000 K.

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* It might be of interest to note why a "perfect" radiator should be known as a "blackbody." When radiation falls on an opaque body, part of that radiation is reflected and part of it is absorbed. Of course, the blacker a body is, the less it reflects and the more it absorbs. And since it has been found that the emissive power of a body is directly proportional to its absorptivity, a body for which the reflectivity is zero and the absorptivity is 100%, is the best possible radiator. Because such a body would absorb all incident radiation and thus be as black as any body could possibly be, a perfect radiator is therefore known as a "blackbody." By the same token, a less efficient radiator is known as a "graybody."

Suppose we were to continue heating the "blackbody" poker. It would get hotter, and its color would change from red to orange to bright yellow. At about 3200 K it would be a yellowish white color, such as the color of the tungsten filament of an "inkie" light bulb. A tungsten lamp, therefore, which emits light of this same color, has a color temperature of 3200 K. *Any* object, whether or not it is hot, has a color temperature of 3200 K if it emits light of this yellowish white color. Now, consider a firefly which emits a greenish white light. To heat our poker to a temperature at which it would emit light of this color would require that we heat it considerably hotter than 5000 K. The firefly is "cold," yet it has a color temperature in excess of 5000 K!

If we could heat our poker until its actual temperature became as high as 10,000 K, we would find that it was "blue hot." The blue sky has a color temperature of 10,000 K or more, yet its actual temperature is below freezing. We know that the blue color of the sky is due to scattering of the blue wavelengths of sunlight. This color is the same color as a blackbody heated to an actual temperature of 10,000 K, or more.

We noted that our iron poker was not really a blackbody; we only assumed it to be one in order to clarify the concept of color temperature. As a matter of fact, no practical light source is a perfect or blackbody radiator, although some sources such as the sun and a tungsten lamp filament are fairly close approximations. For this reason a source such as a tungsten filament is sometimes called a "graybody" source, or a "gray emitter."

An important characteristic of a blackbody or a graybody light source, and one which is particularly important for color photography, is that the relative amount of radiant energy emitted changes gradually from wavelength to wavelength. Such a source is said to have a smoothly varying spectral emission curve. The sun and a tungsten filament are sources of this type, whereas a fluorescent lamp, as we have seen, shows large and erratic fluctuations in light output from wavelength to wavelength. A mixture of two or more light sources of different color temperature, both of which are essentially graybodies, may also result in an emission curve for the mixture which departs considerably from the spectral energy distribution of a graybody source. A mixture of sunlight and skylight sometimes behaves in this fashion, as we shall see later on.

A light source which does not have a smoothly varying emission curve is not only undesirable for color photography, but it is also deceptive if we try to evaluate its spectral energy distribution (the amount of light output at each wavelength) by determining its color temperature. Remembering that the color temperature of a light source refers to the *actual* temperature of a blackbody source which is a *visual* color match for the source in question, this is not too difficult to understand. The concept of color temperature relates light sources which look alike to the eye. Knowing as we do the ability of the eye to adapt, it becomes easy for us to realize that a light source which has peaks and valleys in its spectral emission curve (and thus may be almost lacking in radiant energy at some wavelengths) may *appear* to be a color match for a source such as a tungsten lamp, which has a smoothly varying emission curve. Both sources might have a color temperature of, say, 3200 K; yet while they look alike to the eye, some objects illuminated by them might photograph quite differently. This is what has happened in the top two illustrations of Fig. 4.

SUBJECT CONTRAST AND LIGHTING RATIO

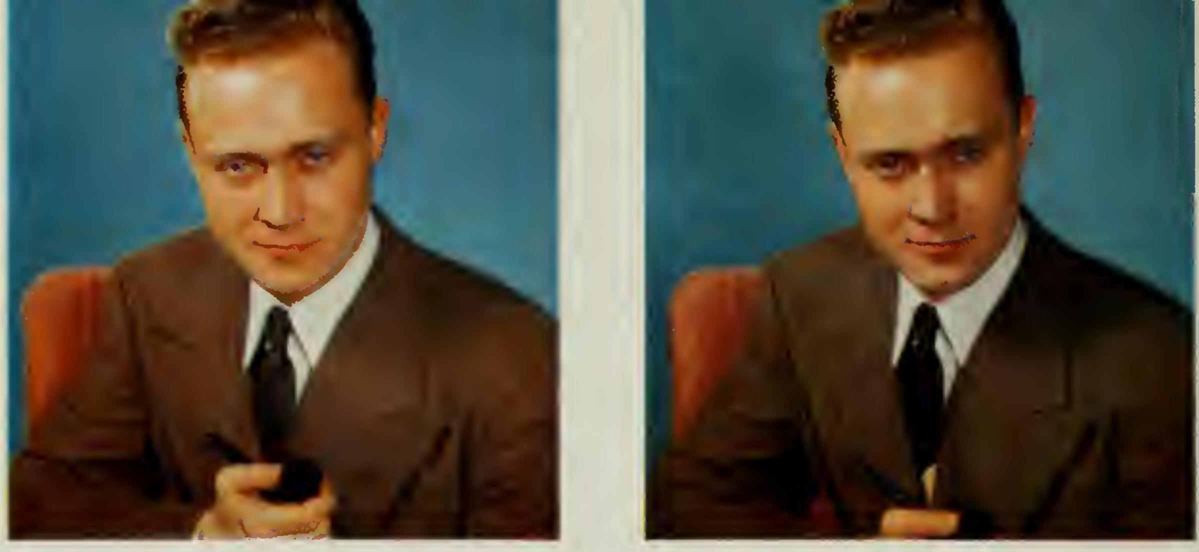
At first glance, subject contrast might be considered to be a property of the physical subject matter (persons or objects) before the camera lens. Suppose, for example, that we photograph a man wearing a white shirt and a dark suit. If the shirt reflects eight times as much light as the suit, and these are the lightest and darkest objects in which detail must be reproduced, we might assume that the subject contrast ratio (the brightest object divided by the darkest) is 8 to 1. Actually, 8 to 1 is the *reflectance ratio.* Subject contrast involves an additional and very important factor — *lighting contrast.*

Lighting contrast can be defined in several ways, and there is yet no standard definition. One way to define lighting contrast is in terms of lighting ratio, as follows: that ratio between keylight plus fill-light and fill-light alone. Let us assume that we are going to photograph a girl using the simplest type of lighting, involving the use of only two lamps. One might be placed on a line forming an angle of about 45 degrees with the camera lens. This would be the main light or *keylight.* The shadows cast by this single light would be very dark, and would obscure some of the important detail of the side of the face furthest from the light. To soften these shadows we might place another light of equal strength on the other side of the camera. This would be a "fill" light, because it fills with light the shadows caused by the keylight.

Now the areas illuminated by both the keylight and the fill-light would receive two units of light, while the areas illuminated by only the fill-light or only the keylight receive but one unit. If the keylight were replaced by another unit twice as strong as the fill-light, the areas illuminated only by the fill-light would receive one unit, but the areas illuminated by both lamps would now receive three units. The *lighting ratio* (ratio of "key" plus "fill" to "fill" alone) is now 3 to 1.

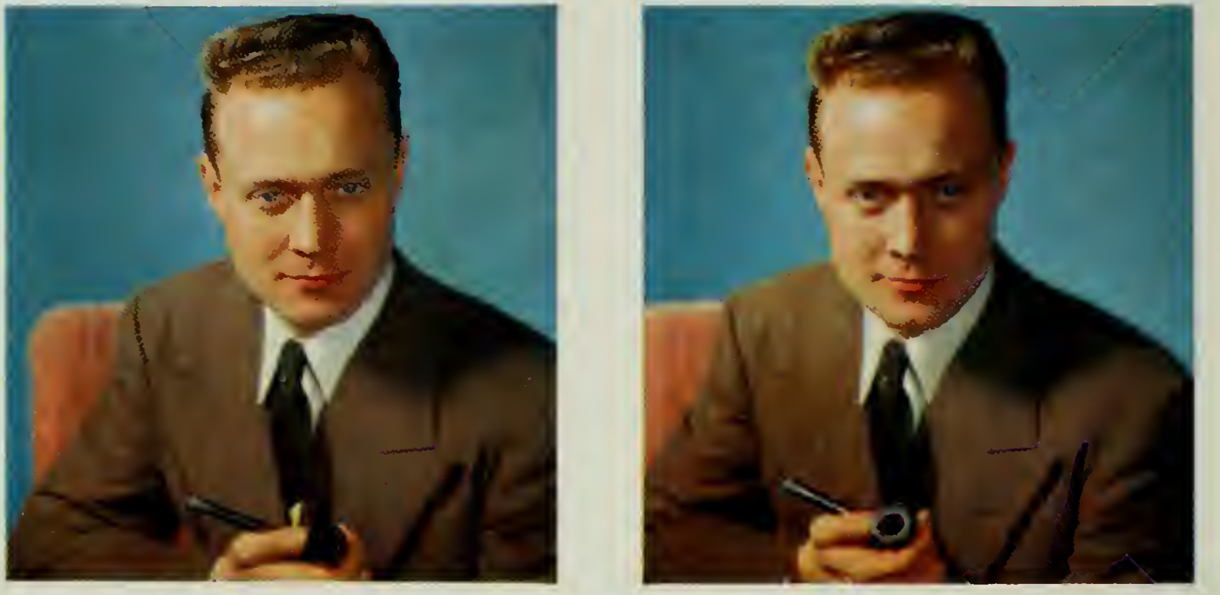
With this arrangement, let us now return to our man with the white shirt and dark suit. Recalling that the reflectance ratio of shirt to suit is 8 to 1, with a lighting ratio of 3 to 1 an area of our subject's shirt which is illuminated by both keylight and fill-light will be eight times as bright as an area of his suit illuminated by both units. But an area of his *shirt* illuminated by *both* units will be *24 times* as bright as an area of his *suit* illuminated by the *fill-light only.* Thus the subject contrast is the product of the reflectance ratio of the subject (8 to 1) and the lighting ratio (3 to 1) — in this case 24 to 1. The reflectance ratio in some scenes can be controlled by a wise choice of color values, as we have seen. In many scenes, however, the reflectance ratio is established by the nature of the subject, and lighting offers the only practical method of contrast control.

Even in black-and-white cinematography, a skilled director of photography exercises care in lighting in order to reproduce detail in both dark and light objects in the same scene. Color films, employing three balanced emulsions, do not have the contrast latitude of a single emulsion, and therefore require "softer" basic lighting. Dark-colored and light-colored objects in the same scene cannot be reproduced successfully in color unless the lighting is adjusted to offset the more extreme differences in tone. Otherwise dark areas will produce too dark and off-color, while light areas will be "burned out," lacking both color and detail. In general, the lighting ratio for color cinematography is not allowed to exceed approximately 3 to 1. Higher ratios than this are used only for special lighting effects. The series of pic-



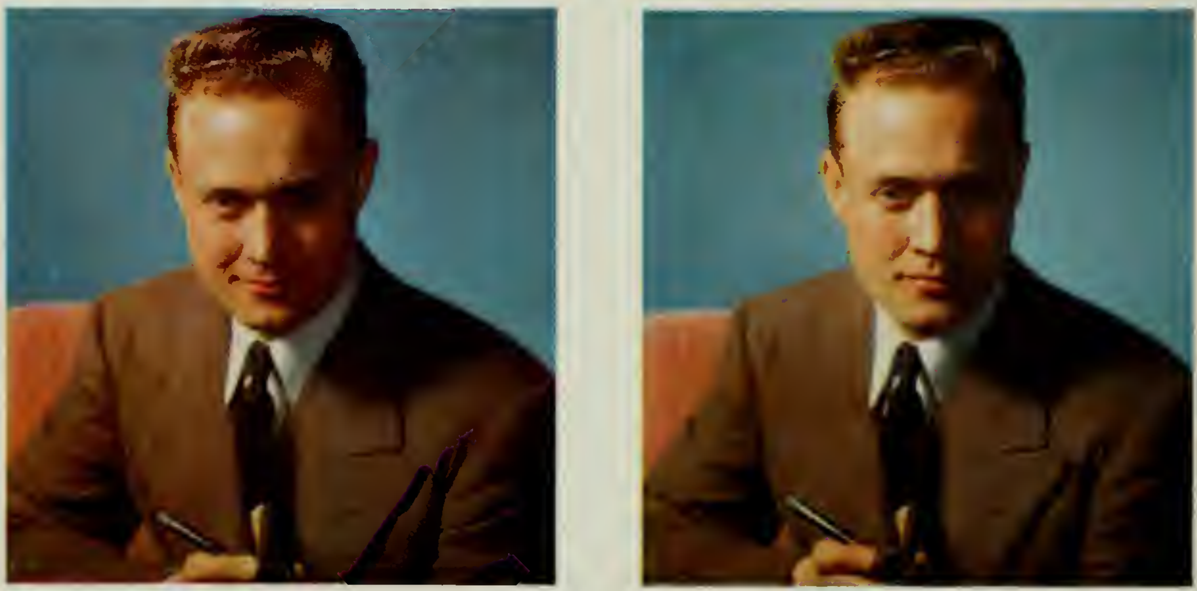
Lighting ratio 2:1.

Lighting ratio 3:1.



Lighting ratio 4:1.

Lighting ratio 8:1.



Lighting ratio 16:1.

Lighting ratio 32:1.

FIGURE 15: Effects of variations in lighting contrast.
(Courtesy Eastman Kodak Company.)

tures shown in Fig. 15 illustrates the results obtained when the same subject is photographed at various lighting ratios.

If the reflectance range of the subject is low, a correspondingly higher lighting ratio can be used without exceeding the subject contrast which a color process can handle. In color cinematography, however, color contrast accomplishes a part of the subject delineation which can be secured only through tonal contrast in black-and-white cinematography, and high-contrast lighting is not as necessary for brilliant results. In this respect, though, the color cinematographer has considerably more latitude than a color photographer whose camera original film will be used to produce a paper-backed color print. Higher lighting contrast is possible when the final color print will be viewed by projection, because the projected image can retain a much greater range of tone values than any type of image viewed by reflected light.

So far we have been considering subject contrast principally in terms of indoor lighting, which allows complete control of lighting contrast by variations in the placement of the lights. In outdoor work, the sun can generally be regarded as the keylight and the sky as the fill-light. On a clear day the ratio of sunlight plus skylight to skylight alone usually gives a lighting ratio which is too high for satisfactory detail in both shadow and highlight areas, especially with side-lighted or back-lighted subjects. We therefore reduce the lighting ratio by supplementing the skylight illumination in the shadow areas, either with "booster" lights or with reflectors which direct sunlight into the shadows. "Scrimming" the sunlight to reduce its intensity is another way of reducing the lighting contrast outdoors. On a hazy day the ratio of sunlight to skylight is lower, and the natural lighting is therefore softer. Consequently, less supplementary lighting is required on a hazy day.

EXPOSURE ACCURACY

Compared to black-and-white films, color films have much less exposure latitude. In other words, the difference between the greatest and the least amount of exposure which will produce a satisfactory color reproduction is much less. This is primarily due to the fact that three light-sensitive emulsions are involved in color, instead of the usual one. Lens and shutter settings must therefore be determined more accurately when we photograph in color.

Color negative films have somewhat more latitude than color reversal films, particularly on the over-exposure side. For best results, however, color negative films must be exposed with considerably more care than black-and-white. In determining the camera lens and shutter settings at which color film will be exposed, a photoelectric exposure meter is almost always used.

7. Color Photography Outdoors

DAYLIGHT COLOR QUALITY

When pictures are photographed outdoors we actually have, as we discussed earlier, two distinct sources of illumination. We have light arriving directly from the sun, and we have the blue light arriving from the sky. These two sources, which together constitute "daylight" illumination, are separate and distinct on a clear day, but fused and combined into one source on an overcast day.

Daylight color quality on a clear day consists of nearly equal amounts of red, green and blue light. Color camera original films which are balanced for this type of illumination are no longer in use for professional color motion pictures, with the exception of a small amount of 16mm Kodachrome film balanced for daylight. Today most camera original films are balanced for tungsten illumination of color temperature 3200 K. When this film is used for photographing outdoors, a color balancing filter which changes the 5900 K daylight (sunlight plus skylight) to 3200 K color quality is used on the camera. This is preferable to having both a 5900 K film and a 3200 K film used on the same picture, for they could be accidentally interchanged without proper labelling of a container, and so ruin expensive photography. Films balanced to 3200 K are preferred to daylight films because most of the light used on sets today is tungsten light. Too, there is less light lost when filtering 5900 K light to match 3200 K film than when filtering 3200 K light to match 5900 K film. Moreover, sunlight is free, and the light lost in filtering has not cost anything; tungsten light requires electric power, and is costly.

COLOR TEMPERATURE APPLIED TO DAYLIGHT

We have seen that the color temperature of a light source is useful in describing some light sources for color photography. We noted that a "graybody" source like an incandescent tungsten filament has a smoothly varying emission curve, emitting energy at all visible wavelengths, and emitting at each wavelength an amount of radiant energy which is proportionate to that emitted by a blackbody source. We noted that the sun and a tungsten lamp both behave essentially as graybodies, and that the color temperature of these sources was therefore adequate to describe their spectral energy distributions and hence the way they would be "seen" by a color film. We also noted that certain mixtures of graybody illuminants of different color temperature, such as sunlight and skylight, may result in an illuminant mixture which departs considerably from the spectral energy distribution of a graybody source. Let us consider further this mixture of sunlight and skylight, which we call daylight.

The color quality of both sunlight and skylight varies considerably, depending upon the time of day, time of year, the location and the condition of the atmosphere. The spectral energy distribution of daylight often departs considerably, therefore, from that of a blackbody or a graybody radiator at a given color temperature. In other words, while we can specify the color temperature of daylight and thus describe its appearance under a variety of conditions, its energy distribution under many of these conditions might not be correct for use with "daylight" color films, which are balanced for a so-called average condition represented by bright sunlight and a clear sky.

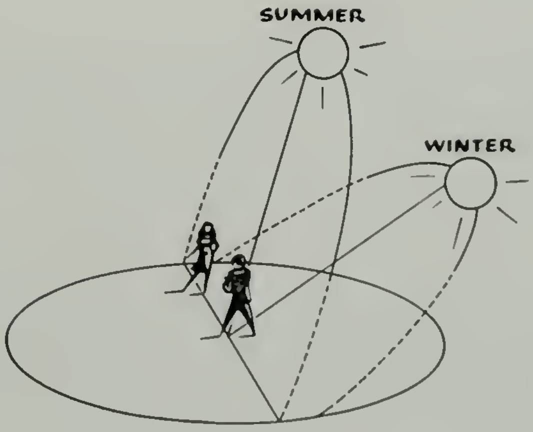
VARIATIONS IN COLOR QUALITY

Time-of-Day Changes

During the hours shortly after sunrise and shortly before sunset, more scattering of sunlight takes place than at other times of the day. This is because at these times the sun's rays must travel a greater distance through the earth's atmosphere. The sun's light is therefore not only less intense, but quite deficient in blue (which is scattered most) and to a lesser extent deficient in green. Pictures photographed by light of this quality (on film balanced for daylight) have a warm cast in the areas receiving direct sunlight, while the shadows tend to be abnormally blue. As we saw earlier, the color of the sunlit areas cannot be corrected by filtering at the camera without making the shadows still bluer. Conversely, we cannot correct for the abnormally blue shadows without making the sunlit areas still redder. We have two different light sources *of different color quality* involved — sun and sky.

As a general rule, the reproduction of a scene on color film tends to be too warm in balance when the sun is less than 15 or 20 degrees above the horizon; but unless the sun is within a few degrees of the horizon, our eyes compensate for the color differences involved. The warmth of the scene is not particularly noticeable in viewing it, but the photographic effect is nonetheless marked. During the winter months there are fewer hours of daylight, and there are fewer hours when the color quality of daylight is "normal" for color photography, as shown in Fig. 16.

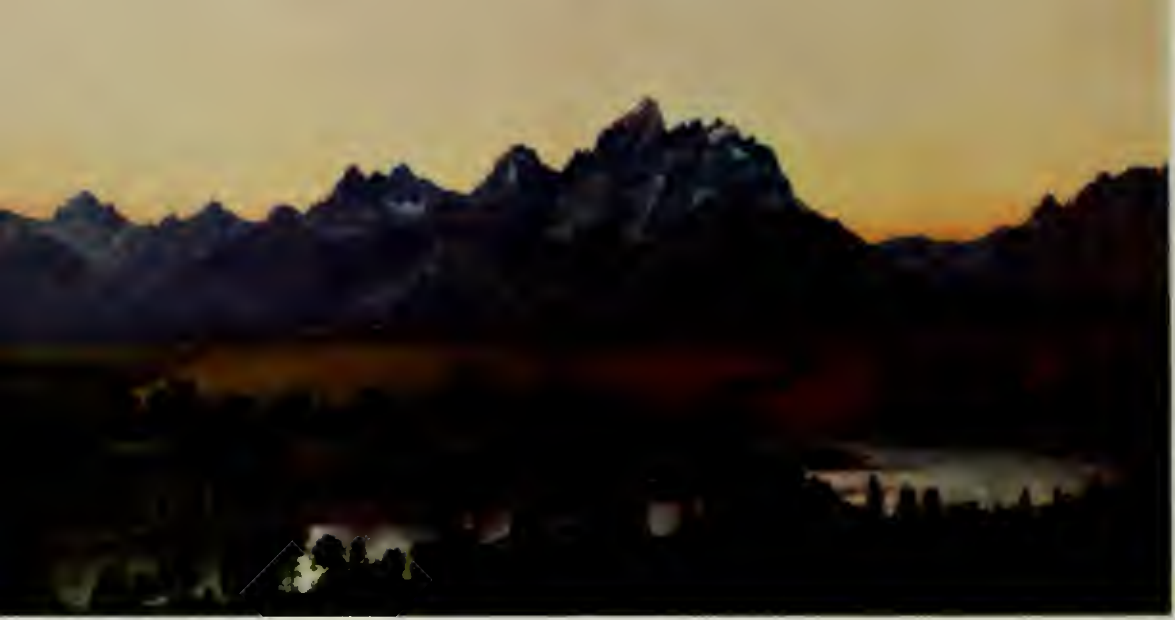
Selecting the time of day for photographing in color can be extremely important, as demonstrated by the illustrations of Fig. 17. Here are shown six pictures, each creating a completely different mood and feeling, yet all of them made without changing the camera position.



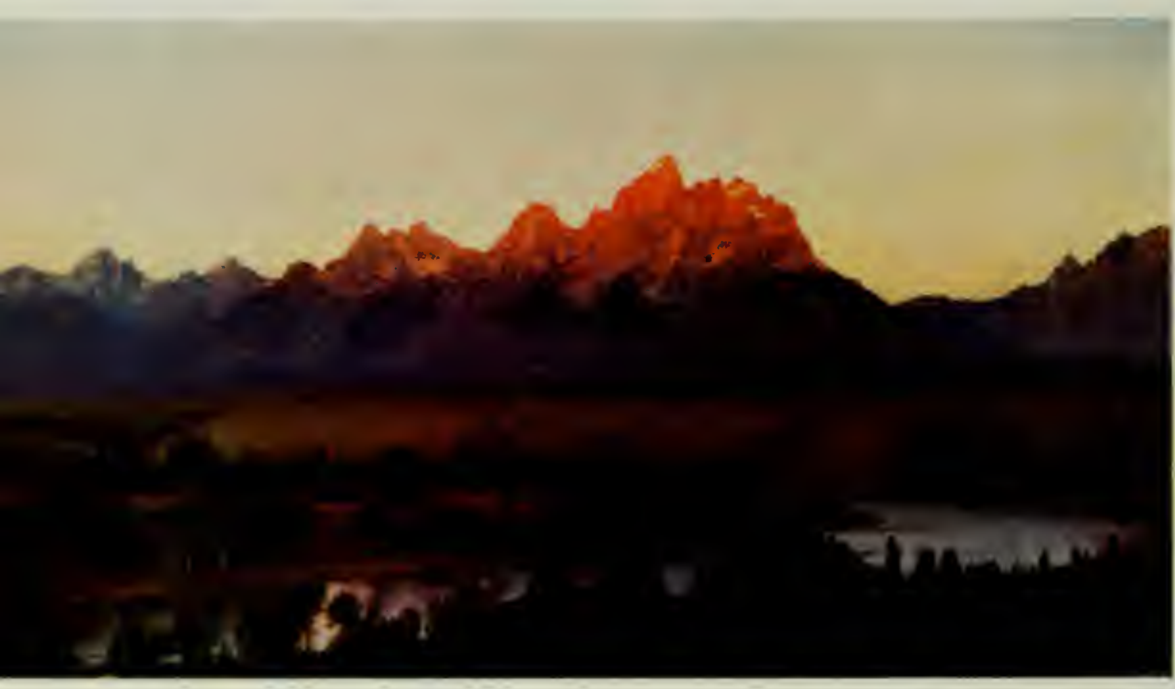
The hours during which pictures with normal color balance can be obtained in the northern latitudes are represented by the solid portions of the two arcs. The greater length of the dotted portion of the winter arc shows how the sun takes longer to reach an angle of approximately 20° above the horizon.

FIGURE 16
(Courtesy Eastman Kodak Company.)

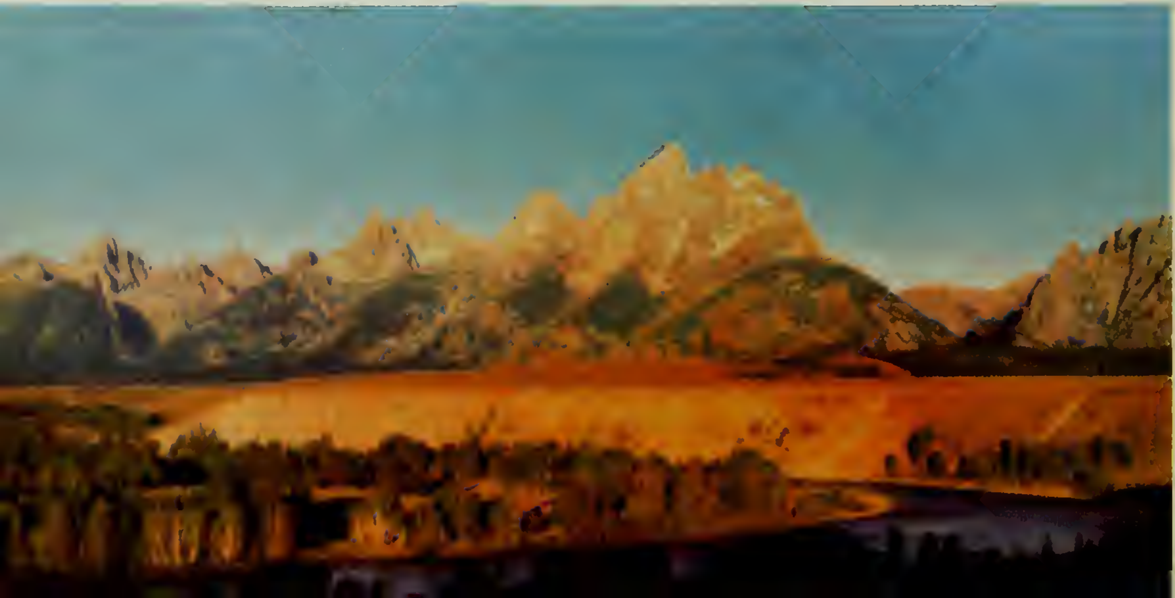
FIGURE 17 **(pages 60 and 61)**
(Courtesy Eastman Kodak Company.)

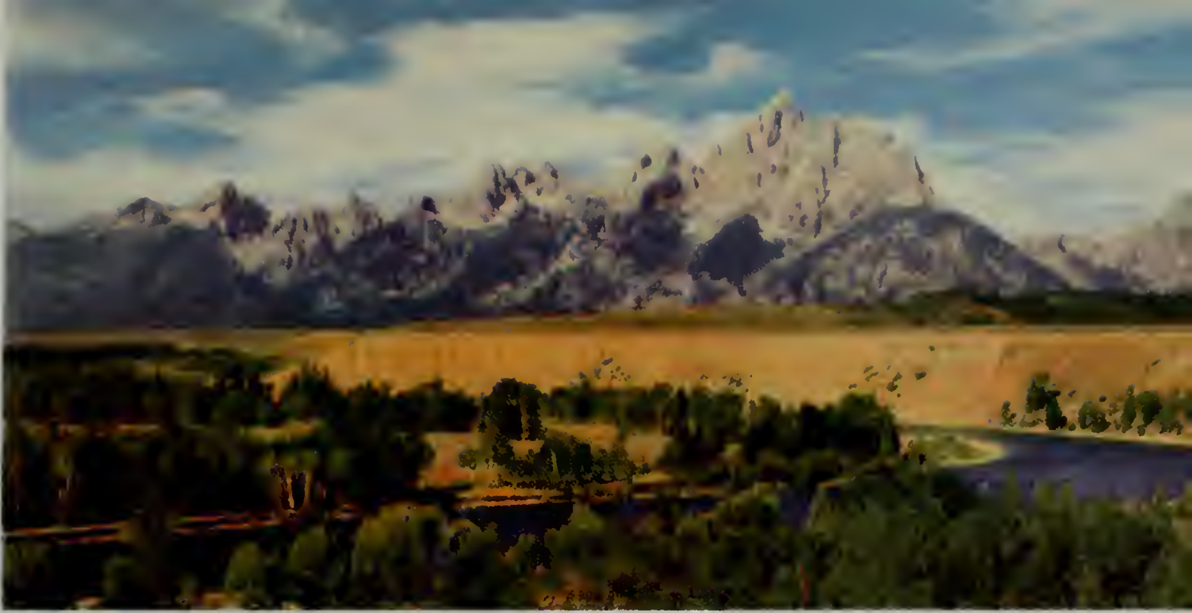


Pictures made at various times of day show the effects of changes in the lighting direction and in the color quality of the light. (Above) Before dawn—scene illuminated only by blue skylight.

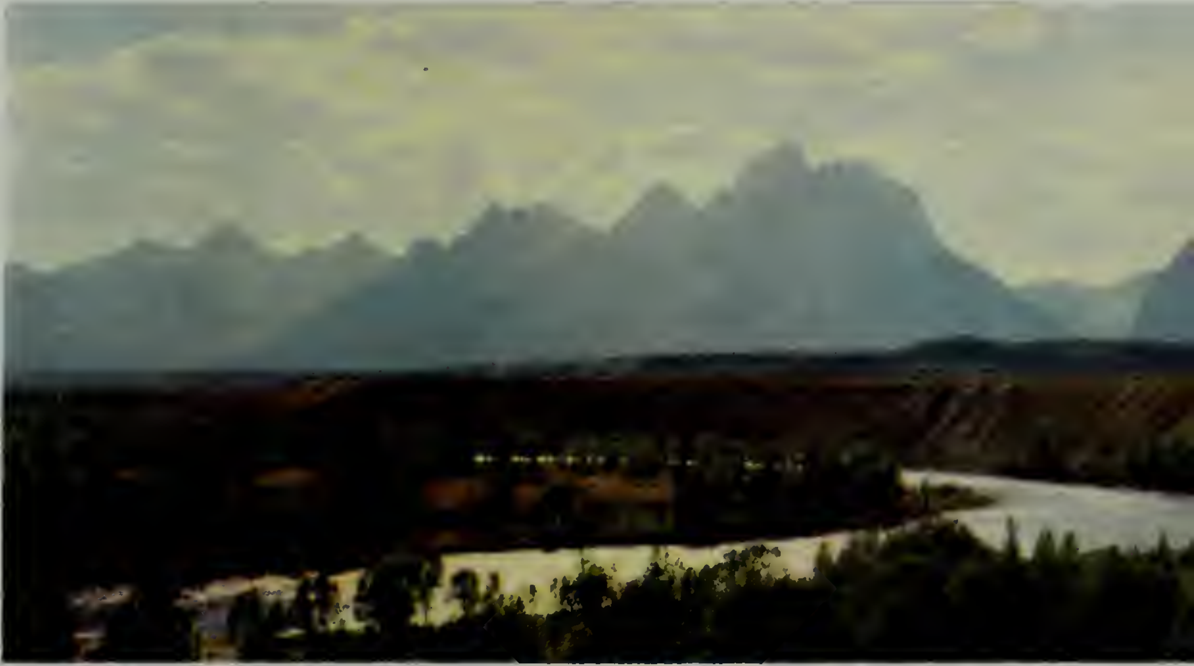


(Above) Reddish sunlight just hitting the peaks, foreground still illuminated by blue skylight.
(Below) Early morning sunlight reaching the foreground—the color of the light is still very warm.

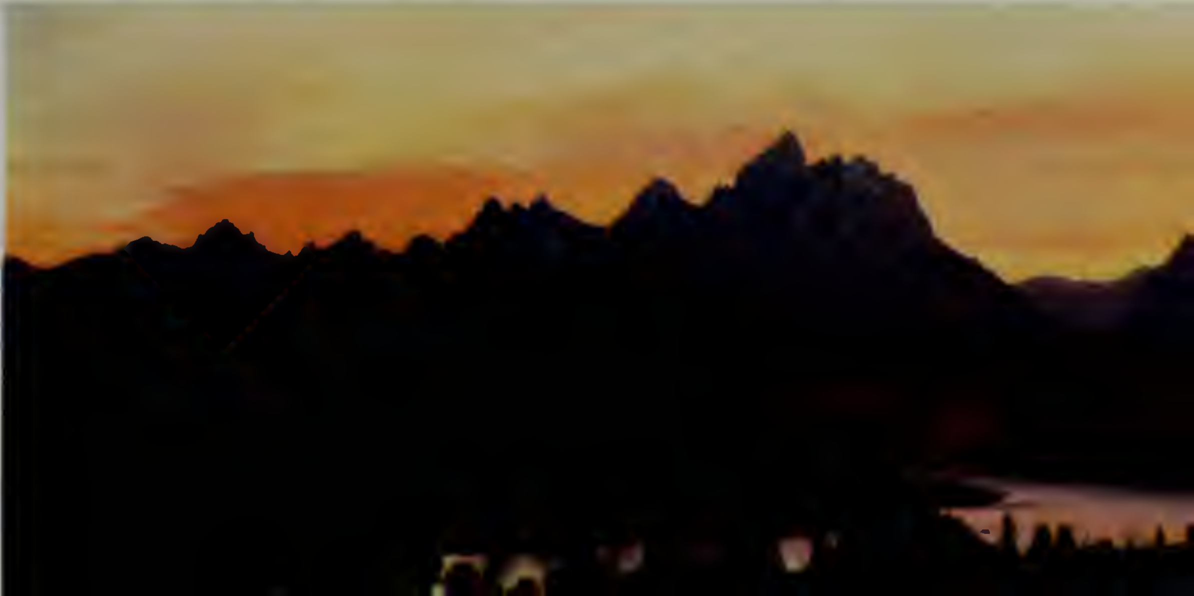




(Above) Strong side lighting—normal color balance and good color saturation in all parts of the scene. (Below) Back lighting has emphasized distant haze and lent an atmospheric quality.



(Below) After sunset. This is only one of several different pictures made late in the day. From Kodak Ektachrome transparencies taken at Grand Teton National Park by Ansel Adams.



Type-of-Day Changes

The light from the sky and the light from the sun falling on a subject on a clear day are different, as we have seen, by 5000 K or more. On a day when haze or clouds are present, however, these two sources of illumination become less different. Light haze and large white clouds tend to reflect sunlight into the shadows, lightening them and minimizing the bluishness which is normal when shadows are illuminated only by clear blue sky.

On a completely overcast day when the lighting is such that no distinct shadows are cast, the sun and sky are effectively combined into one large, diffuse source. The absence of shadows and of sunlit highlights gives a characteristic flat appearance to a scene. This flatness is emphasized by the low color saturation created by the diffuse lighting. The color quality of an overcast day is somewhat bluer than normal daylight illumination on a clear day.

Open-Shade Conditions

Subjects photographed in open shade on a clear day are shielded from the direct rays of the sun, and illuminated only by skylight and light reflected from nearby objects. People photographed on the shady side of buildings tend to have an overall bluish cast, especially in the flesh tones. Shadow areas of scenes which are strongly side-lighted or back-lighted are also quite bluish. This effect is particularly noticeable in snow scenes, and scenes which contain light objects such as white houses. The degree of bluishness depends on the depth of color in the sky, the presence of clouds which might act as reflectors, and the degree of clarity of the atmosphere. Early or late in the day, the effect of skylight is more pronounced because the intensity of sunlight relative to that of skylight is reduced.

LIGHTING AND SUBJECT CONTRAST

Illumination outdoors on a clear day can be compared in a general way, as we have said, to the keylight and fill-light used in the studio. The sun, of course, corresponds to a hard, undiffused, keylight, and it accounts for a large proportion of all the light falling on a subject. The sky can be compared to large, diffuse fill-lights.

The intensity of the light from the sun is relatively fixed; but the intensity of skylight varies over wide limits, depending upon the area of the sky open to the subject, the presence or absence of clouds, and the amount of haze.

On a perfectly clear day when the sky is a deep blue, the illumination from the sun is approximately 9500 foot-candles. (A foot-candle is a technical term defined as the light received from one candle at a distance of one foot.) The sun, then, corresponds to 9500 candles one foot distant. In addition, about 1500 foot-candles are provided by the blue skylight. Thus we have a total of about 11,000 foot-candles in the sunlit regions of a scene. For a subject which receives light from a large, unobstructed sky area, then, the lighting ratio is 11,000 to 1500, or about 7 to 1 on a clear, sunny day.

When the sky is completely overcast and the sun is obscured, all the light falling on a subject arrives from the sky. Although the illumination level may go as low as 200 foot-candles on a heavily overcast day, the light is almost uniform over most of the scene. The highest lighting contrast on any particular subject outdoors, then, is obtained with a clear sky and a bright sun about 7 to 1 with the normally used variations of front-lighting technique. It may become many times greater than this if the scene is back-lighted or side-lighted, and if the shadow regions are shielded from the sky by trees or other nearby objects.

Because the human eye tends to compensate for both brightness level and brightness differences, it cannot be relied upon as a means of evaluating either the illumination level or the lighting contrast. On overcast days or in shaded areas the illumination level appears to be higher than it actually is. Under such circumstances a photoelectric exposure reading will indicate the need for more exposure than what is estimated by visual means. The eye also tends to peer into the shadows and adapt itself to that level. An exposure meter reading will show that in order to reproduce the shadow detail on the film more fill-light must be added compared with what is estimated visually.

Subject Contrast Variations

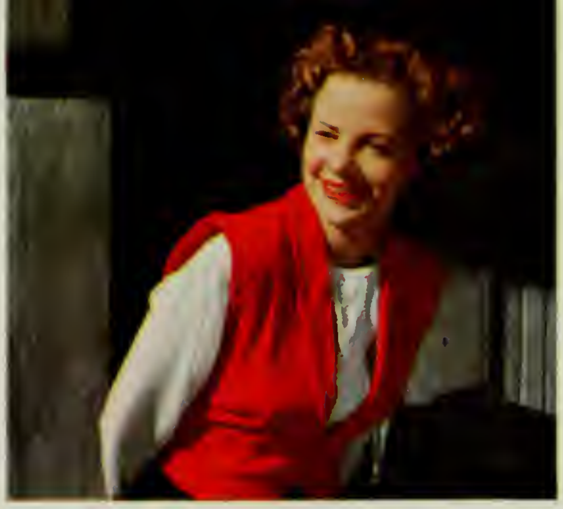
Although the *average* (overall) reflectance of an outdoor scene is about 12%, some areas such as sand, flesh tones and yellow flowers reflect a great deal of light, whereas areas such as green foliage, dark-colored clothing and dark buildings reflect very little of the light falling on them. As we saw earlier, the combined effect of the reflectance range of a scene and the lighting contrast ratio controls the subject contrast, or, as it is frequently called, the *brightness range,* of the scene. We have seen that the reflectance ratio of any particular outdoor scene cannot be altered readily, and that to control the brightness range of the scene we must control the lighting contrast.

Shadows are "filled" out of doors by using either reflectors or "booster" lights to reduce the normal lighting ratio of sunlight to skylight. Only "silver" or "lead" reflectors can be used on color pictures. The "gold" reflectors often used for black-and-white throw yellow light into the shadows, creating an extremely abnormal effect. Arc booster lights, which emit light of daylight quality, are often used. Tungsten lights are rarely used outdoors since they must be used with MacBeth (blue) filters to change them from a color temperature of 3200 K to 5900 K to get an approximate match for average daylight. This means the tungsten lamps first must be filtered to match daylight, then refiltered at the camera back to 3200 K again, since film balanced for illumination of this color quality is used.

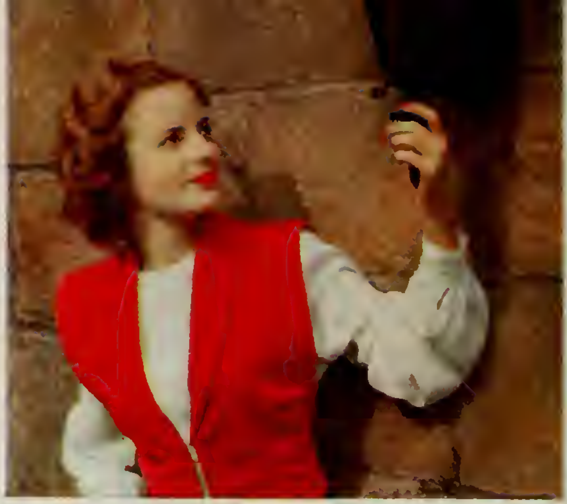
EFFECT OF LIGHTING ON COLOR SATURATION

Almost everyone has recognized the fact that colors in pictures photographed on a clear day are more saturated and more brilliant than colors in pictures photographed on a cloudy day. We know, for example, that soft, pastel colors tend to be grayed down and lose their pleasing appearance when the day is overcast, and this effect is more pronounced as the distance from the camera to the subject is increased.

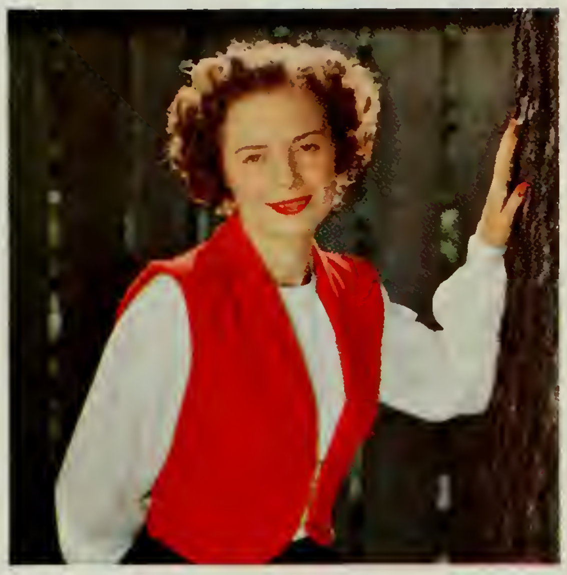
When light is reflected by a colored object, most of the light falling on it penetrates the surface, as we have seen, and is colored by the dye or pigment through which it passes. Some light, however, is reflected from the surface without ever penetrating the coloring matter beneath. This light is white; that is, the color of the light source. It mixes with the colored light reflected from the object, desaturating the depth or body color. The more directional the light source, the more easily can these white, surface reflections, known as "specular" reflections, be kept from reaching the film by proper replacement of the camera and subject with respect to the light source. On a cloudy day, with the light from the sky reaching the subject from all directions, it



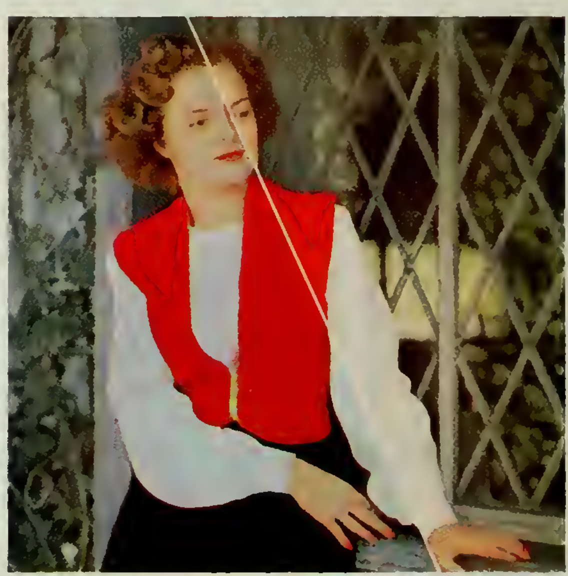
Bright Sun—Contrasty lighting with heavy shadows.



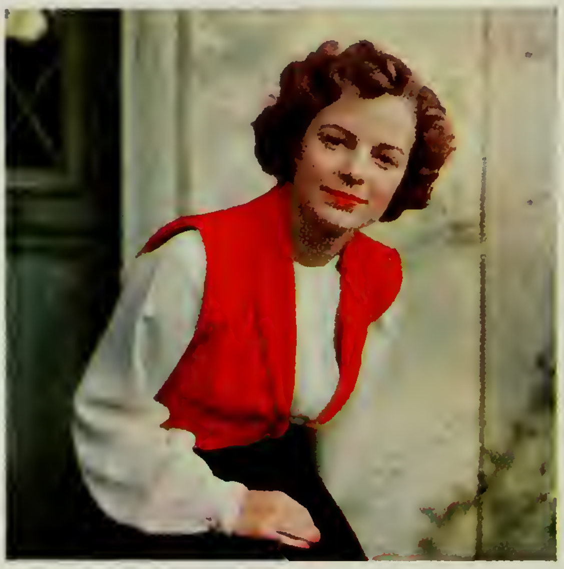
Hazy Sun—Soft and pleasing lighting for close-ups.



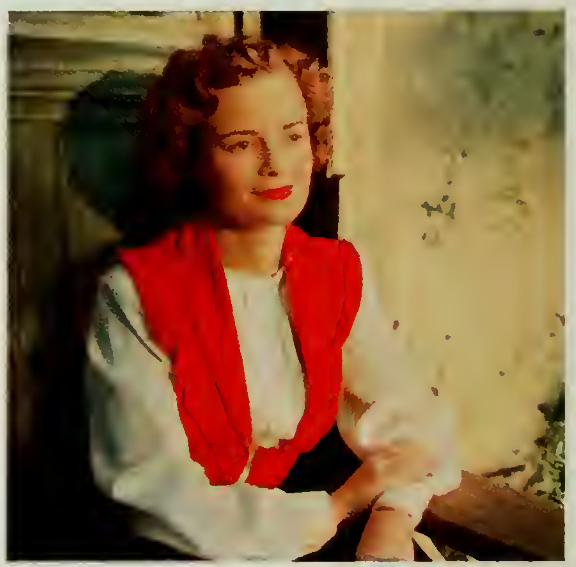
Back Lighting—Supplementary illumination by reflectors.



Open Shade—Blue skylight. (Right) With Skylight Filter.



Cloudy Bright—Dull, lifeless lighting; poor flesh tones.



Sunset—Note warm flesh tones and blue shadow regions.

FIGURE 18: Effects of various outdoor lighting conditions.
(Courtesy Eastman Kodak Company; from Kodak Ektachrome Transparencies by H. F. Mayer, Eastman Kodak Company.)

is impossible to orient the subject in such a way that the specular reflections from the surface can be directed away from the camera. Loss of color saturation results.

Sometimes on a clear day it becomes desirable to have diffuse light outdoors for closeups. The use of a "scrim" — a large, white, cheesecloth screen — between the sun and the subject will soften the shadow lines and subdue the highlights resulting from the "hard," directional rays of the sun. In this application the scrim acts in the same way atmospheric haze does to reduce the lighting contrast.

Figure 18 shows the effect of various outdoor lighting conditions.

SPECIAL PROBLEMS OUTDOORS

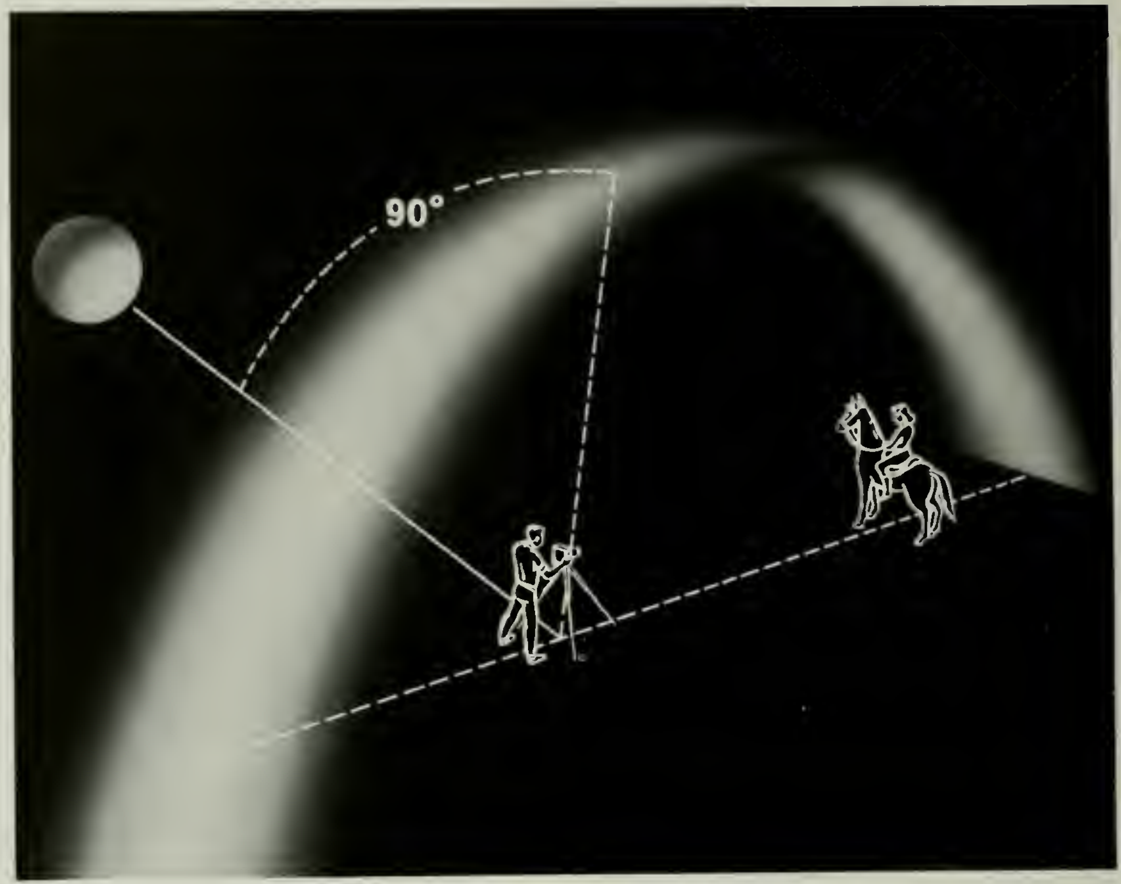
Filters

When photographing on black-and-white film, filters are often used to remove entire regions of the visible spectrum, as was shown in Fig. 1. This is done in order to help the black-and-white film reproduce the various parts of a scene in terms of brightness differences about as our eyes see them; or to achieve dramatic effects, usually by darkening the sky so that the contrast between clouds and sky is increased. Filters for color photography are not designed to remove whole sections of the spectrum, but only to accentuate one particular color or another. Because only slight changes in color balance are usually required, these filters are much less saturated than those used for black-and-white photography.

A light orange-pink filter is used for converting daylight to 3200 K illumination, and conversely, a light bluish filter is used for converting tungsten light (3200 K) to daylight (5900 K). A pale pink filter, known as a haze or skylight filter, is used in open shade under a clear blue sky to improve color rendering, which would otherwise be too bluish. This same filter is also useful for reducing the bluish cast of distance haze.

Obviously a yellow filter cannot be used with color films as it is with black-and-white films for the purpose of darkening the sky, for a yellow filter would remove blue light not only from the sky, but from every other part of the scene as well. A polarizing filter, such as a Kodak Pola-Screen, can, however, be used for this purpose. Although not a filter in the customary sense of the word, the effect of a polarizing filter is to increase the color saturation of some reflecting surfaces, to darken the blue sky, and to a limited extent to penetrate light blue haze. The maximum of haze penetration and darkening of the sky takes place in a region approximately at right angles to the direct rays of the sun, as shown in Fig. 19. "Panning" the camera along the white arc from one horizon up through the zenith (the point directly overhead) and down to the opposite horizon will aim it in the direction of maximum effect. Note that when the sun is directly overhead, the camera must sweep around the horizon for maximum sky darkening and haze penetration.

A polarizing filter works because it is able to screen out light which is vibrating in one particular plane — that is, light which is polarized. Skylight and light blue haze are more or less polarized by the scattering process. Polarization is at a maximum at angles of 90° and 270° with the direct rays of the sun, and at a minimum at 180°. The darkening effect thus is zero with the camera pointing directly toward the sun, increasing to a maximum at 90°, decreasing to zero again at 180°, increasing to a maximum again at 270°, and decreasing to zero again as we approach the sun in our 360° sweep. Because the "glare" from some nonmetallic surfaces is polarized, a



Maximum darkening of the sky by a polarizing filter over the camera lens takes place in a region at approximately right angles to a line extending from the sun to the camera.

FIGURE 19 **(Courtesy Eastman Kodak Company.)**

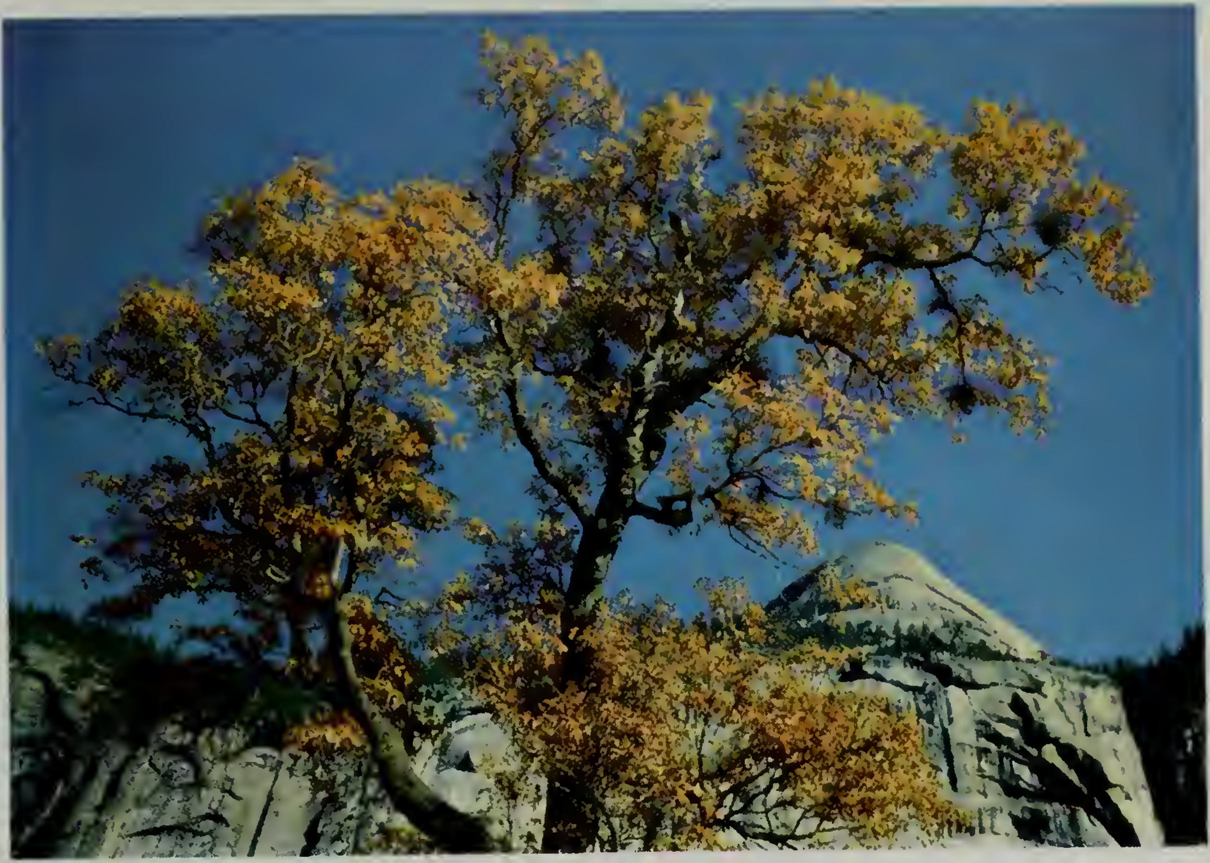
polarizing filter can also be used to remove these unwanted reflections. It is a most useful tool in landscape photography, where, under ideal conditions its effects can be very marked, as shown by the two illustrations of Fig. 20.

Sunrises and Sunsets

Color pictures made at sunrise or at sunset can be strikingly beautiful. The brightness range of a sunset or a sunrise is many times greater than that which color film can reproduce, however, and if we are to achieve maximum saturation in the reproduction of the sky colors we must adjust the exposure to favor the bright sky regions. For this reason no detail can be recorded in the shadow areas, and people or objects in the foreground usually stand out as silhouettes against the colored sky.

Aerial Photography

If color pictures are to be made from the air, it is important to wait for the clearest day possible, for the amount of blue haze encountered in photographing from the air is much greater than that encountered in photographing distant landscapes. If even a slight amount of haze is present, the use of a haze or skylight filter is advantageous from all but the lowest altitudes. Side-lighting is usually preferable to flat-lighting, unless bad haze is a problem, for shadows cast by objects which are side-lighted make those objects stand out from their surroundings. Back-lighting is generally avoided, for it tends to produce an overall bluish veil



Above, without "Pola-Screen"; below, with "Pola-Screen." Note the dramatic effect of the darkened blue sky and the increased color saturation in the leaves. From Kodak Ektachrome transparencies taken at Yosemite National Park by Ansel Adams.

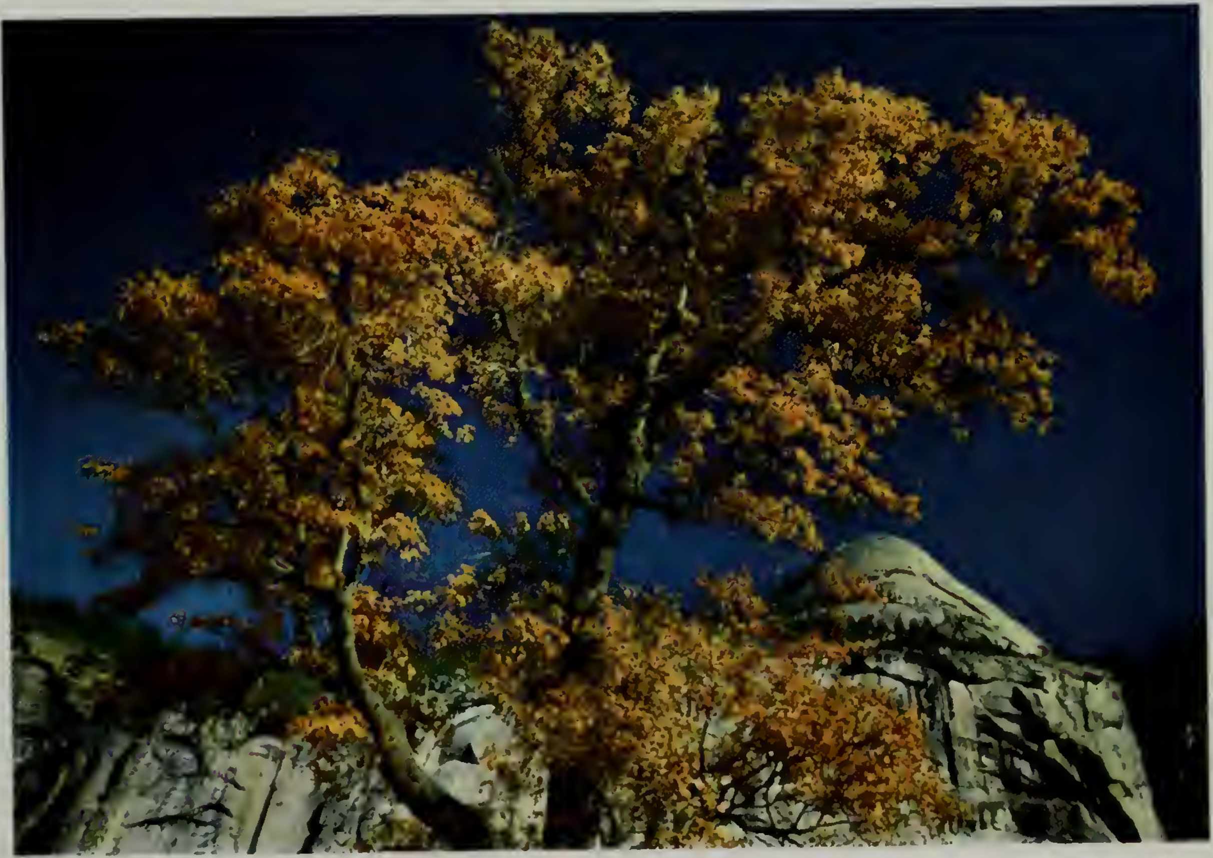


FIGURE 20
(Courtesy Eastman Kodak Company.)

caused by scattering of blue wavelengths by smoke or dust particles.

Night Photography

Motion pictures shot outdoors at night require artificial light, obviously, and so really are pictures shot on an outdoor stage. There are exceptions, of course, such as street scenes which are photographed by the illumination of the street lights themselves. On close shots, however, studio lighting units are generally used, at least for keylights.

Day for Night Photography

Some night scenes required by motion-picture scripts, such as a long shot of a grazing herd of cattle, are of such scope as to be impossible to light artificially. Such scenes must be shot in daylight, but must be made to look as though they were photographed at night. Usually they are carefully underexposed to yield negatives that are "thin," but in which color balance and detail are not lost. These negatives can then be printed dark to achieve a night effect. Too, some technique for darkening the sky is usually employed, since, if the sky is lighter than the landscape, the scene can easily be recognized as an underexposed day shot. A polarizing filter is usually employed for this purpose.

Photography in the Tropics

The impression is frequently held that there is more light available in the tropics than in temperate climates. Several factors contribute to this erroneous impression. In tropical regions which are characterized by very clear atmospheric conditions, the lighting ratio is usually very high. As a rule the sun shines more frequently in such regions, but the length of day is less than at high latitudes during the summer. Also, the subject material native to these tropical regions usually has a greater brightness range; tropical foliage is generally very dense and absorbs a great amount of light. As a result, exposures frequently have to be increased above the normal exposure required in temperate climates for outdoor scenes in which foliage appears.

Because the sun is more directly overhead for a longer part of the day in tropical regions than in non-tropical regions, the lighting tends to be strong top-lighting, requiring more supplementary illumination. Where no additional illumination is available for photography during the middle part of the day, more exposure is required.

Photography at Low Temperatures

At the very low temperatures sometimes encountered in northern winters, in the Arctic or Antarctic regions or at high altitudes, the speed and color balance of color films is sometimes unpredictable. Normally this is not serious, but certain color compensation for color changes in backgrounds and costumes may have to be made if important colors are to match indoors and outdoors at low temperatures.

8. Color Photography in the Studio

LIGHT SOURCES

Lighting equipment for color motion pictures is, in the main, the same equipment which has been used for black-and-white pictures. Arclamps of various sizes are used as keylights on large sets where light of great carrying power is required. Since the color films currently used in the studios are balanced for 3200 K light, arclamps, which produce illumination of daylight color quality, require the use of a correction filter, such as the Mole-Richardson MP-2, to change their color balance to 3200 K. Tungsten incandescent ("inkie") lights are used as keylights on small sets, for fill, backlighting, and for background illumination. "Inkie" lights, of course, normally require no correction filters when used with 3200 K film.*

Good maintenance on arclamps is very important. The light is generated by an electric spark jumping a gap between two carbon electrodes. The carbons are consumed in the process, the positive carbon being consumed rather rapidly in the larger lamps. This carbon must therefore be motor driven toward the negative carbon at a constant rate. If this drive is not constant, the gap between the two carbons varies, resulting in a change of color quality of the light.

The voltage applied to the lighting circuits is also important, both for arclights and for tungsten lights. On an arc, a moderate drop in voltage results in a loss of light output, the change in color quality of the light being negligible. With "inkie" lights, however, both the light output and the color temperature decrease. If all the lamps on a set are inkies, so that all decrease in color temperature in about the same amount, such a change in color quality can be compensated for later, during printing — provided, of course, that the drop in color temperature has not been too great. If, however, filtered arcs and inkies are mixed on the set, or if the voltage on one inkie circuit remains constant or increases while the voltage on another inkie circuit decreases, then some of the lamps will change color relative to others.

Let us suppose that we are shooting a close-up. If the voltage at the keylight is normal and the voltage at the fill-light is low, the flesh tones will tend to go red in the shadows — a most unpleasant and unnatural effect. This same effect can be produced by using too many diffusing "silks" to soften or to reduce the intensity of fill-lights.

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* Those who work on the studio stages may detect an apparent discrepancy here, since the color camera films used are balanced for light of 3200 K, while the tungsten lamps used are rated 3350 K. However, 3200 K film has some latitude both above and below 3200 K, provided the light on the set is of a uniform color temperature. The difference between 3200 K and 3350 K is within this latitude. Too, the voltage on the lamps will often vary from the rated voltage, usually down, depending upon the electrical load on the stage and in the studio. This tends to reduce the color temperature of the lamps.

Light of the correct color quality can best be secured by operating inkie lamps at exactly their rated voltage. If this is impossible, correction can be obtained by using the proper filter in the camera, provided the voltage on all the lines varies in the same direction. The color temperature of an inkie light varies about 10 K for each change of 1 volt.

Fortunately for the color cinematographer, there is very little change in color temperature as an inkie light bulb ages with use. A tungsten lamp bulb can blacken to a point where the light output is reduced to less than one-half its original value, and still maintain a fairly constant color temperature.

LIGHTING RATIO AND DISTRIBUTION

We have seen that the basic lighting contrast for any color process should be fairly low, or "soft." We have also seen that this does not mean we are limited to flat, uninteresting illumination. It means, rather, that to achieve the modeling effects we desire we need lower lighting ratios than those used in black-and-white photography. In color, with color differences affording much of the separation between various portions of the scene to be reproduced, the tonal contrasts may be excessive unless lighting effects are subtly used.

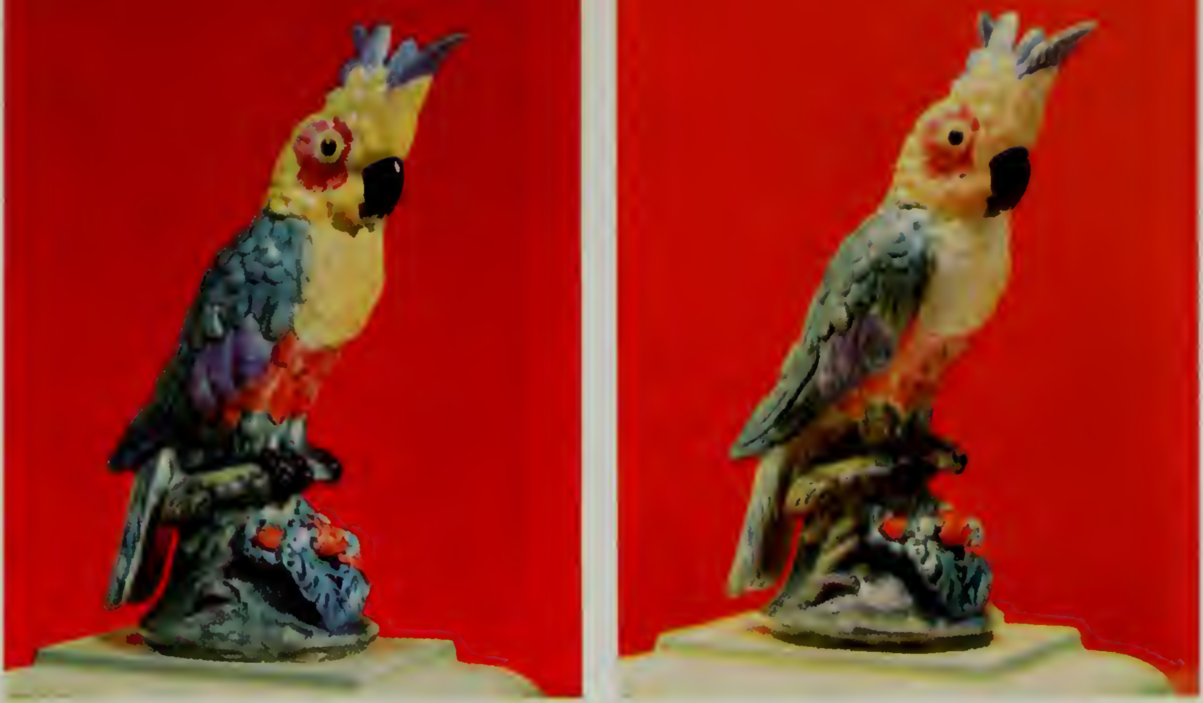
As we know, the permissible lighting ratio is somewhat flexible, depending upon the color contrast and the extent of light and dark areas in the scene. In general, the lighting ratio indoors should not exceed 3 to 1 for average subjects. With subjects that do not contain a wide range of reflectances, 4 to 1 can be used. If a release print is to be used for color television broadcasting, lighting ratio should not exceed 2 to 1 because of the more limited contrast range which can be accommodated. For special lighting effects, the lighting ratio may frequently be as high as 10 to 1 or more. Detail in the shadows is completely lost, of course, when ratios as high as this are used.

Lighting setups on the studio stage are generally more elaborate than those used outdoors. Camera lights, top-lights, "eye" lights, "outline" lights, "accent" lights — these are a few of the many types of fill-light which are used exclusively on the stage.

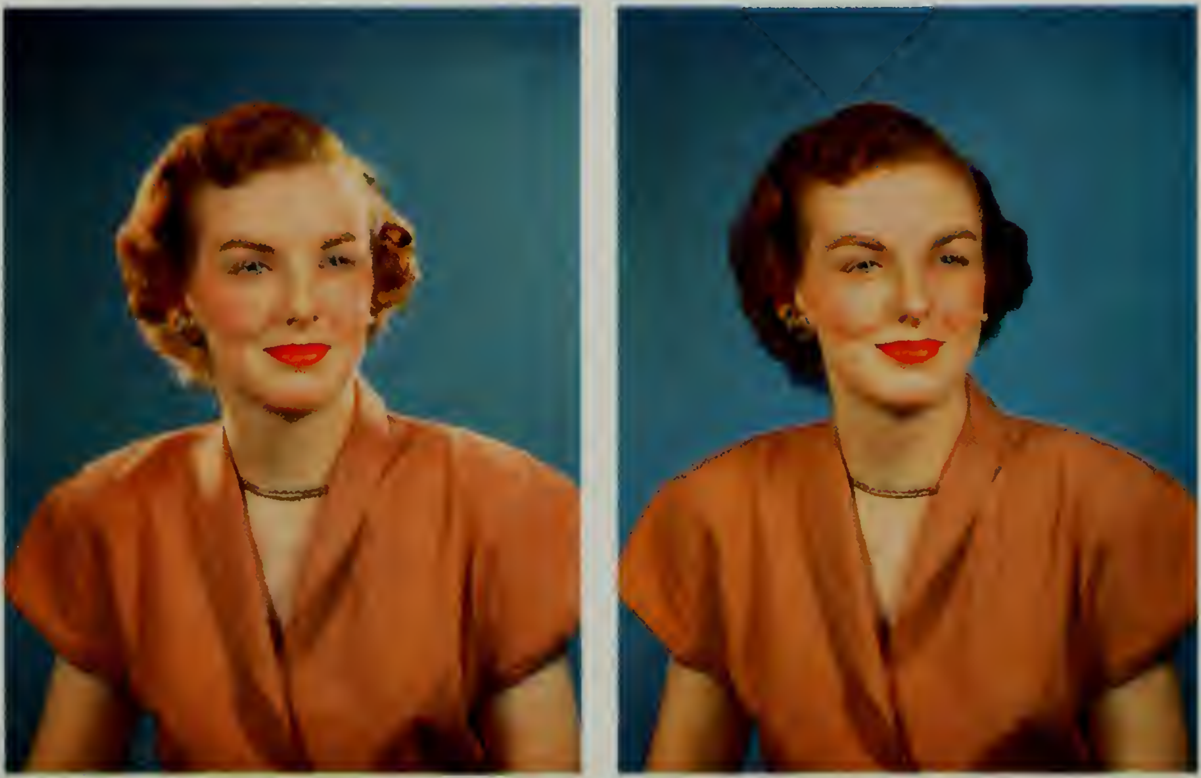
When photographing in color, adequate illumination must be provided over the entire scene if normal color rendering is to be obtained. If this is not done, there may be areas which will be reproduced so dark that color and detail are lost. Such areas are difficult to detect when viewing the original scene, another result of the ability of our eyes to adapt to variations in light levels.

Our eyes actually see these dark areas lighter than they are. One way to see the lighting distribution of a scene about as the film will see it is to view the scene through a heavy "neutral density" filter — one which transmits all the visible wavelengths in approximately equal amounts, but which transmits only about 10% or less of the total light coming from the scene. The eye's ability to see into the shadows is significantly curtailed at low light levels; it therefore sees the shadow areas as dark as the film will see them. The best way to check both the lighting distribution and the lighting ratio in the complex lighting setups used on a motion-picture stage, however, is to use a photoelectric exposure meter of the incident-light type.

To measure the lighting ratio, the



The difference in color saturation between these two pictures is due entirely to the character of the illumination. At the left, undiffused spotlights were used; at the right, completely diffused illumination from large white reflectors was used. From Kodak Ektachrome transparencies by J. F. Collins, Eastman Kodak Company.



Although hue differences provide much of the desired separation of subject planes, value differences are also important. At the left, back lighting has been used to improve the tonal separation between the model and the background. From Kodak Ektachrome transparencies by D. N. Sederquist, Eastman Kodak Company.

Figure 21
(Courtesy Eastman Kodak Company.)

meter is held at the position of the principal subject in a scene and aimed at the keylight with all the fill-lights turned off. Then the meter is aimed at the camera with the keylight turned off and all the fill-lights turned on. Suppose the keylight reading is 500 foot-candles and the fill-light reading is 200 foot-candles. The keylight to fill-light ratio is thus 500 to 200, or 2½ to 1. Now we hold the meter at the position of the principal subject and aim it at the camera with *all* the lights turned on. We will get a reading of about 600 foot-candles (not 700, as might be expected). The *lighting* ratio is thus 600 to 200, or 3 to 1. The 600-foot-candle reading is the total illumination level upon which the camera exposure is based.

DIFFUSION ON LIGHTS

"Silks" or frosted glasses are often used on light sources for the purpose of diffusing or "softening" the light. They are useful for reducing the gloss and sheen of many surfaces, but the primary use for diffusers is to eliminate, or at least to greatly reduce, skin texture, especially on close-ups of women.

The proper amount of diffusion is somewhat a matter of personal opinion, although most cinematographers would rather use too little diffusion than too much. Skin usually has a slight sheen, and if a completely diffused lighting is used the natural gloss is lost; the skin will then have a dull, lifeless appearance. Sometimes, however, it becomes necessary to use great amounts of diffusion, not only on the lights but also at the camera. This is often required when making close-ups of women who must appear glamorous, but whose complexions have begun to show unmistakable signs of age. A sufficient amount of diffusion will then destroy the unwanted detail of wrinkles and pores.

If possible, most cinematographers prefer to use the keylight undiffused and to use moderate diffusion on the fill-lights. Here, again, allowance has to be made for the reflection characteristics of individual faces. The comparatively matte skin of a woman wearing a generous amount of powder may require completely undiffused lighting; a dark, oily skin may require a great deal of diffusion.

Control over color saturation is another possible use of diffusion on lights. As we have seen, the saturation of a color decreases with increased diffusion of the lighting. This is especially true of objects having a high-gloss surface. The top two illustrations of Fig. 21 show this clearly.

THE PERCEPTION OF DEPTH

A good color motion picture is unmatched for realism, and this realism owes much to the successful illusion of depth. Just as the apparent shape of objects is influenced by the camera angle, the illusion of depth is determined to a large extent by the way the subject is lighted. Basically, high contrast heightens the illusion of depth, and from the standpoint of depth perception the contrast can be due to either high lighting contrast or high photographic contrast, usually known by the term "gamma." We shall discuss gamma in more detail later. For the present, let us note that the usual aim of film laboratory and film manufacturing techniques is to achieve normal photographic contrast, or gamma. In this way the most effective and pleasing separation of important subject tones can be produced, without unpleasantly distorted colors and brightness values. Since the photographic contrast of a color process is fixed, then, it is up to the cinematographer to arrange his lights in order to obtain the maximum illusion of depth in the reproduction.

Arranging lights to increase depth involves two things. The keylight should be placed toward the side of the subject, or slightly in back of it, and the ratio of keylight to fill-light should not be too low. This does not mean that the lighting should be made contrasty in an effort to avoid flatness. Rather, it means that all the *allowable* contrast should be utilized, and the lights should be positioned properly in relation to the planes of the subject. To show as much depth and roundness as possible, each different plane of the subject should be illuminated so as to have a different tonal value, but the subject contrast ratio should not be higher than the film can reproduce satisfactorily.

Sidelighting is usually used for achieving roundness and depth because it is easier to light the various subject planes differently with a side-light than with a front-light. This can be seen very well from the two illustrations of Fig. 22. The two lower photographs of Fig. 21 show how back-lighting can be used to separate a subject from the background by accenting areas of the model's hair and shoulders to create value differences. The photograph of Fig. 23 is an example of good modelling, depth and plane separation.

CONTROLLING BACKGROUND COLOR

We have seen that the background areas in color motion pictures must be selected with care. They must also be lighted with care if the planned color effect is not to be lost. Too, if it should develop that an available background is too dark or too light, it can often be made to reproduce as desired by increasing or decreasing the intensity of the background illumination. For example, to produce a lighter shade of the same background color, the background illumination might be made about 20% higher than the subject illumination. Since exposure is based on the subject illumination, the photographic reproduction will show a relatively lighter background color with no change in foreground rendering. Likewise, if the background is too light, a reduction of about 20% will cause it to photograph darker. Figure 24 shows an adjustment of this sort.

SPECIAL PROBLEMS INDOORS

Duplicating Sunlight Effects

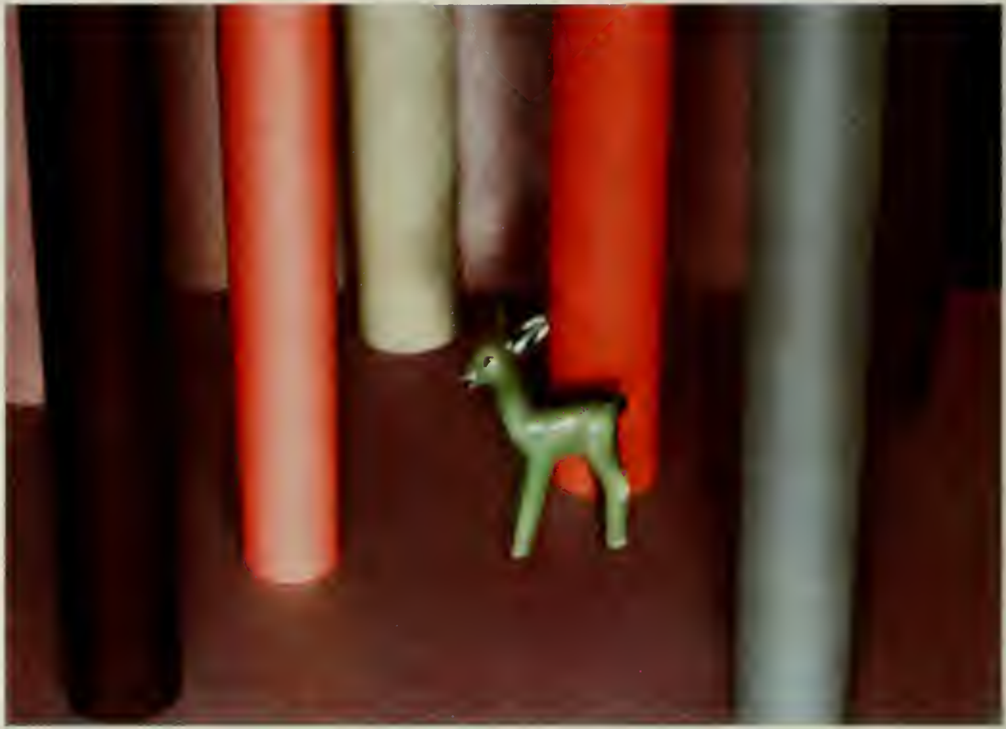
The motion-picture photographer is often called upon to duplicate the effect of sunlight on the stage. Many times these scenes have to be intercut with actual sunlit exteriors. If a convincing illusion of the outdoors is to be created, certain characteristics of sunlight should be duplicated as closely as possible.

The sun is generally considered to be an overhead source. This ideal is so firmly planted in our minds that a picture actually photographed by the low, early morning or late afternoon sun sometimes fails to give the impression of sunlight. *The keylight should illuminate the subject from an angle of at least 30° above the horizon.*

The combination of sunlight plus skylight casts only a single shadow. Obviously a *single* keylight source is needed in the studio to duplicate this effect. Also, the intensity and placement of fill illumination should be such that *no multiple shadows are formed.*

The intensity of sunlight is uniform over the sunlit areas of the scene. Indoors, this effect cannot be duplicated exactly, but it can be imitated satisfactorily by using a large carbon arc-light as far away from the subject as exposure and space will permit.

When the sun is shining brightly,



The perception of depth is affected by the lighting contrast of the scene. The upper scene has diffuse front lighting. The identical scene, with nondiffuse high-contrast side lighting (below), gives a much greater perception of depth.

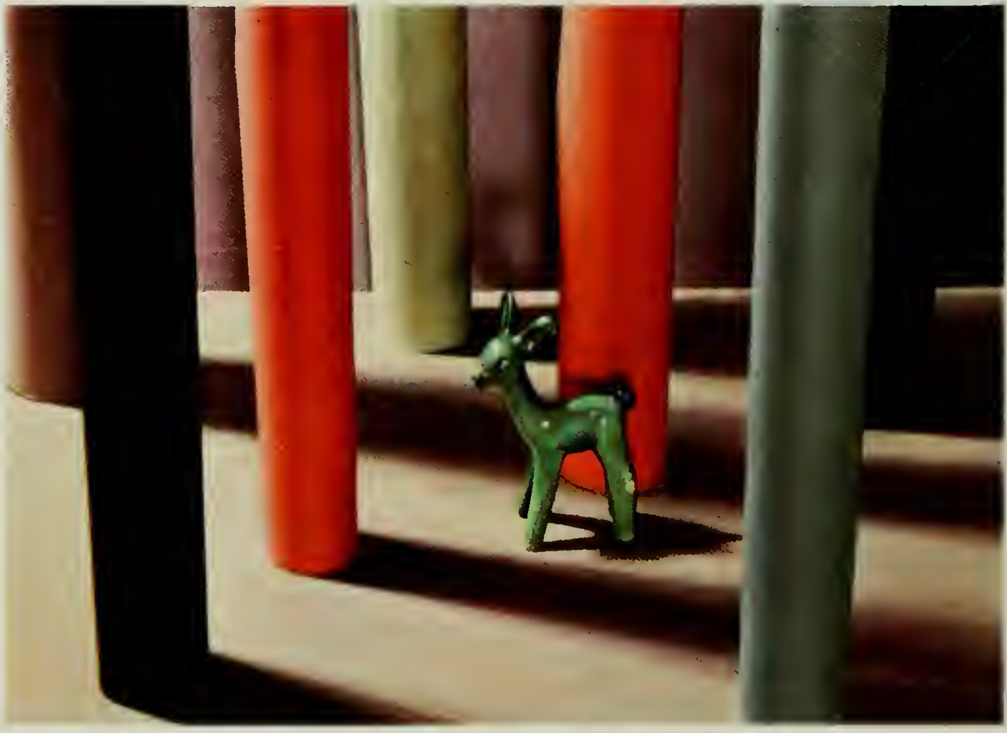


FIGURE 22

(Courtesy Eastman Kodak Company; reprinted with permission from Ralph M. Evans's *An Introduction to Color*, 1948, John Wiley & Sons, Inc.)

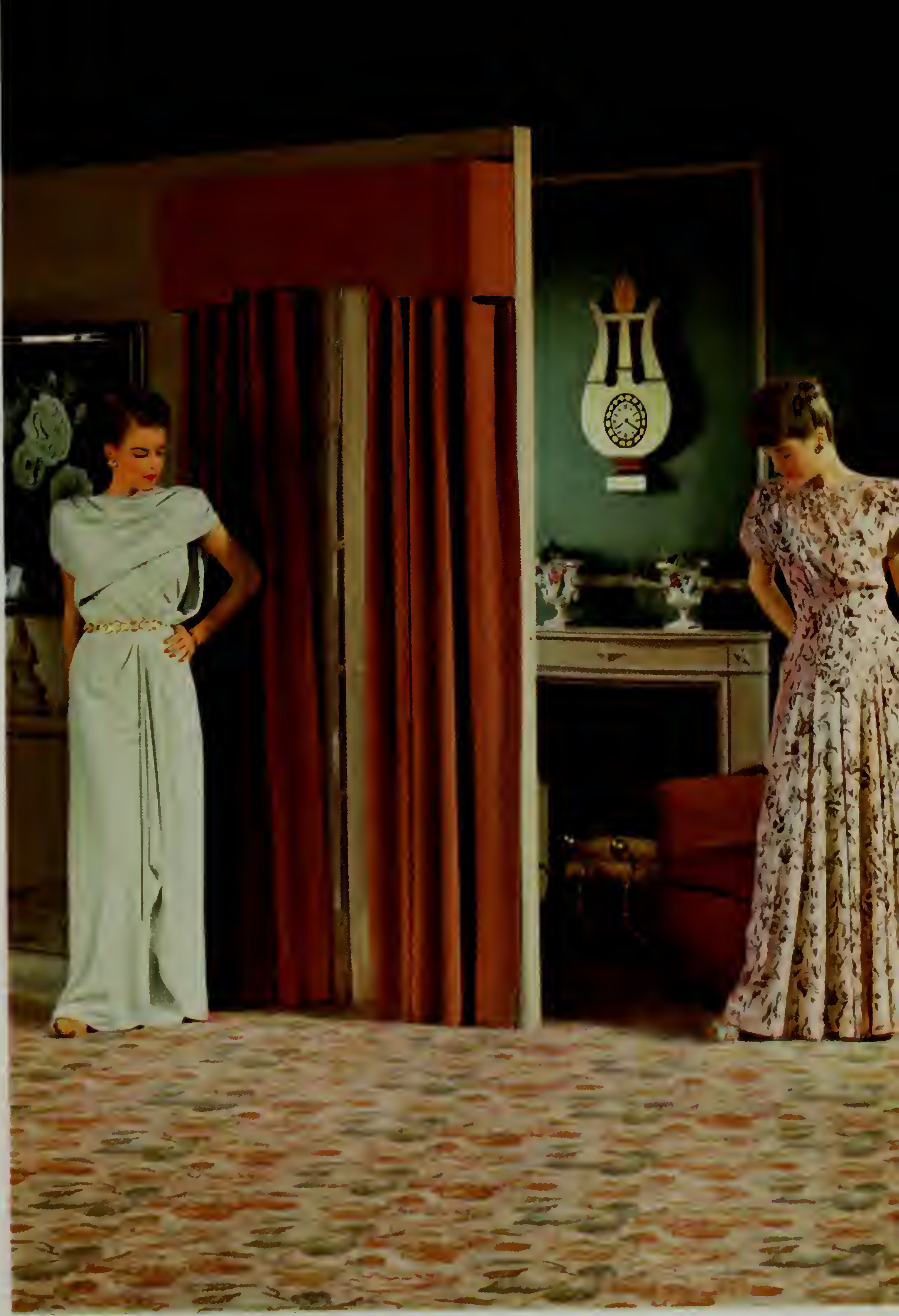


FIGURE 23: A well-lighted interior.
(Courtesy Eastman Kodak Company.)

the ratio of sunlight to skylight is about 7 to 1. The tonal extremes of dark and light objects are outside the contrast range of color films with this lighting ratio, and reflectors or booster lights are normally used outdoors to reduce this ratio to about 4 to 1. Indoors this is considered a contrasty lighting ratio, but *a ratio of at least 4 to 1 is required to create a sunlight effect,* as shown in Fig. 25.

The shadows cast by objects in sunlight have sharp edges. This edge sharpness is due to the fact that the sun is so far away that its rays are essentially parallel. If the edges of shadows are important to a scene, the keylight should be far enough away from the subject that the shadows show the sharp edges characteristic of sunlight.

The sun casts a shadow approximately the same size as the subject. This, too, is because the sun is so distant that its rays are essentially parallel, and the use of a single keylight as far away from the subject as possible is required. A high-intensity, undiffused arclight gives best results.

Shadows in a sunlit scene are bluish compared with the highlights. Sometimes light blue filters are used over fill-lights to achieve this shadow hue indoors. The filters must be very light in color, since all that is required is the mere suggestion of a bluish cast in the shadow areas.

Use of Colored Light

Normally, as we have seen, the color quality of a light source should be that for which the film is balanced. Too, if several light sources are being used to illuminate the subject (as is almost always the case), they should be as nearly alike in color quality as possible. In the hands of a capable and imaginative cinematographer, however, colored lights can be used to create emotional effects for special purposes. Large sheets of colored gelatin are usually employed in front of certain of the lighting units to obtain the effect desired.

Except for intentionally bizarre effects, colored light is seldom used on faces or food, since most people are especially critical of the color rendition of such subjects. A green face or a purple slice of bread, for example, is almost intolerable. Used with discretion, however, colored accent lights can be helpful for such purposes as:

To glamorize, or to create a striking effect for attention-getting purposes. One or more colored lights are sometimes used to illuminate the subject from different directions, but more often the color is confined to the surroundings or the background. This use of colored light is seen in almost every good musical.

To simulate outdoor lighting effects on the stage. Bluish light for moonlight, or yellow or orange light for firelight are examples. Also, bluish light for shadow illumination or for moonlight shining through curtains or venetian blinds.

To produce colored backgrounds by directing illumination of the desired color onto light, neutral backgrounds. A clear blue sky background can be improvised easily in this manner.

To alter or enrich the color of fabric backgrounds or drapes, particularly in shadow areas.

To give the effect of light being reflected from a nearby colored object.

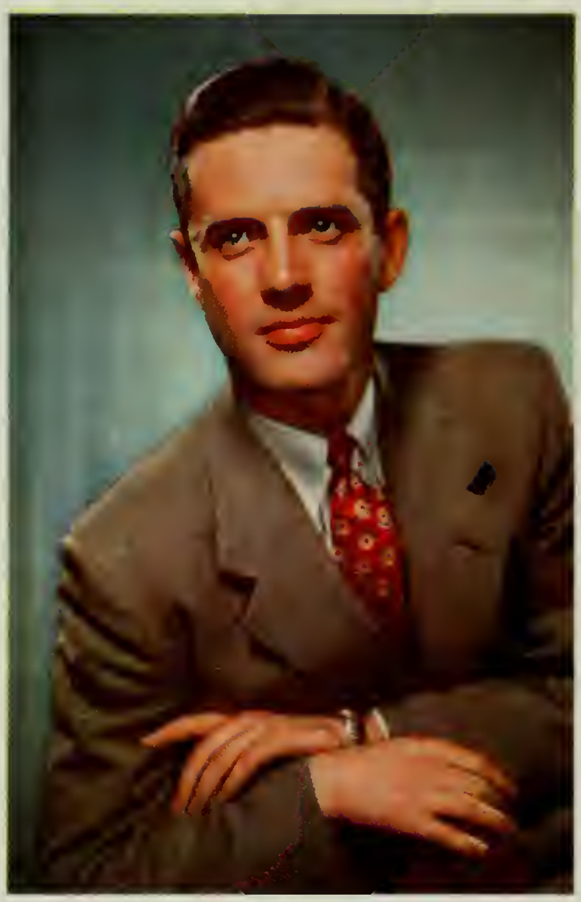
To attain special effects, such as a girl blushing.

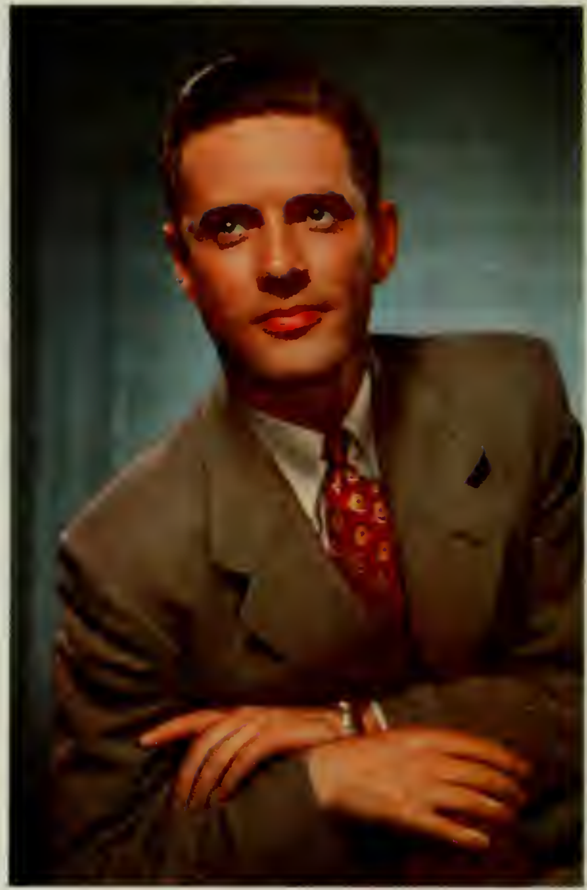
Use of Projected Backgrounds

The effectiveness and versatility of background projection is well known by almost every motion-picture artist and craftsman. Backgrounds may be filmed in remote or distant places and projected on a "background process" screen in the studio, thus allowing actors to play scenes in the studio which would otherwise have to be photographed in these remote or distant places. Too, many dangerous and otherwise impossible shots become possible through the use of projected backgrounds.

The most satisfactory method for using these background films is to project a reversed image from behind the screen. The screen itself must be colorless, show no grain pattern, and transmit light well. Whenever a scene is projected onto such a screen, the illumination tends to be somewhat greater at the center than at the edges on the camera side of the screen. This "hot spot" can be removed by a series of relay condenser lenses on the background projector, or by using a "dodger" in the light beam between the projector and the screen. This dodger is generally opaque and star-shaped, so that when placed in the center of the projector beam it holds back relatively more light from the center portion than from the edge portions of the beam.

The ratio of illumination between the foreground actors and objects and the background images on the screen is important when using projected backgrounds. An exposure meter can be used to bring the two portions of the picture into balance if the background is a "still" or "stereoptican plate." If the background is a motion picture, however, an exposure meter can only be used as a guide to the proper balance, since the shutter of the background projector introduces a factor which must be taken into consideration. The shutter of the background projector is synchronized with the camera shutter, so that the film in the background projector is illuminated only when the camera shutter is open. For this reason a motion-picture background on a process screen looks too dim to the eye when the proper balance between foreground and background has been achieved. Care must be taken to keep foreground illumination from spilling onto the background screen, since stray light will cause loss of contrast and color desaturation in the projected image.





Nearly any medium or light background can be made to photograph lighter or darker by adjusting the amount of illumination falling on it. The illustrations at the right and directly above show the practical limits of this control in a typical case. Appreciably less light than used at the right would make the background appear nearly black in the reproduction; more light than used above would make it appear "burned-out." Note that the model appears lightest in comparison with the darkest background, and darkest against the lightest background. Actually, the same amount of light was used on the model for all three illustrations.

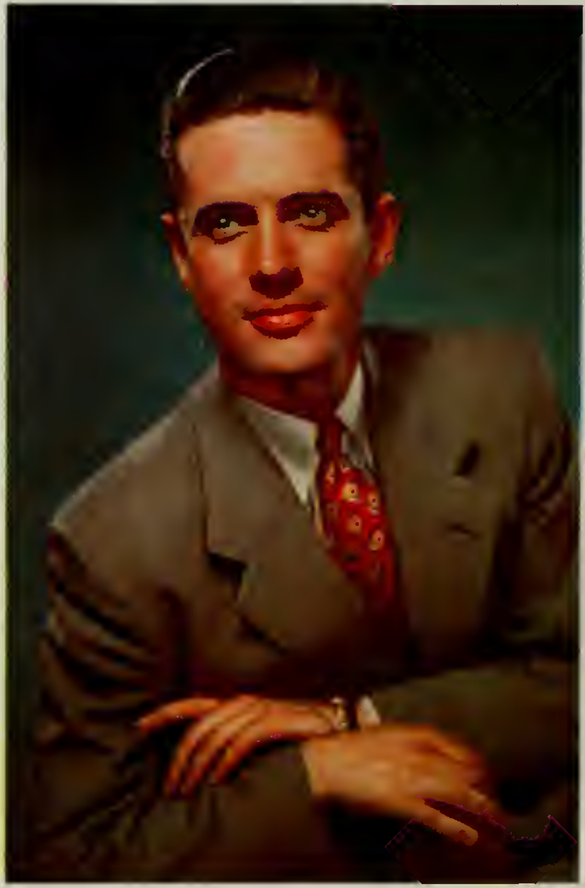


FIGURE 24

(Courtesy Eastman Kodak Company; from Kodak Ektachrome Transparencies by C. O. Baker, Eastman Kodak Company.)

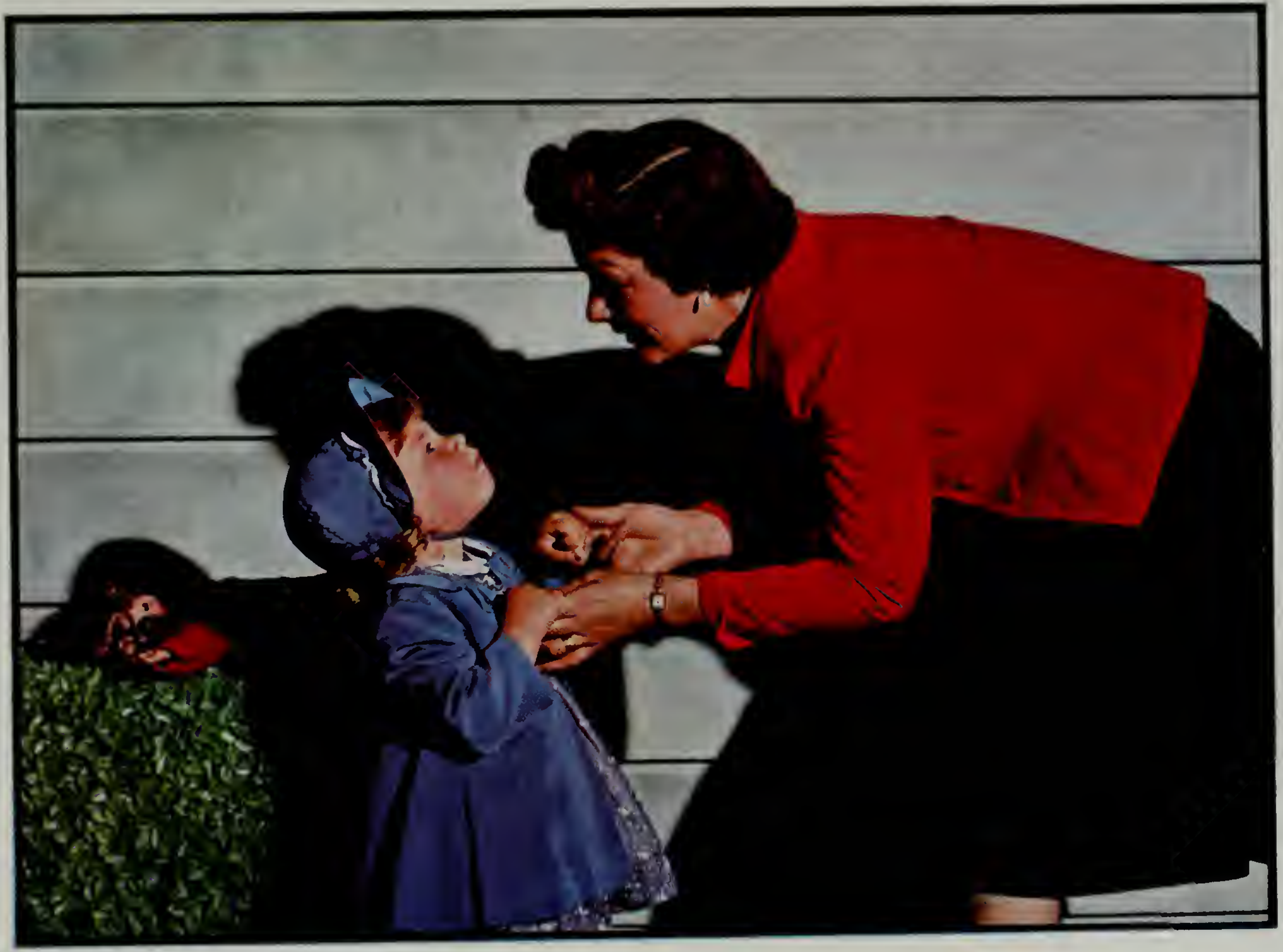


FIGURE 25: Sunlight effect on the stage.
(Courtesy E. I. du Pont de Nemours & Company; from a dye transfer print of an original transparency by Charles Walczak.)

9. Special Effects

Strictly speaking, under the heading of Special Effects we must include all of the visual image devices of a motion picture in addition to and different from the scenes obtained by straightforward photography. Certain effects can be created in the camera, but, except for anamorphosing and background process photography, special effects are usually produced in some form of photographic copying machine from previously prepared photographic material. These effects are almost limitless in number, but the ones most frequently encountered in motion-picture practice are listed below. All of these effects are sometimes referred to as "trick work."

Lap Dissolve: One scene disappears while the next scene simultaneously appears.

Fade Out: The scene grows darker until the screen is completely dark.

Fade In: The scene gradually appears from a completely black screen.

Wipe: A line travels across the screen, on one side of which is the old scene and on the other side the new scene. The line may be horizontal or vertical, straight or curved; the direction of travel may be linear or rotational. Or the effect may take the form of an expanding circle, ellipse, triangle or any other geometric figure or figures. The possibilities are virtually endless.

Superimposure: One or more images may be combined, with one serving as the background for the others.

Split Screen: A single performer is shown in a dual role, or visualizing himself engaged in some additional action.

Titles: Name of the picture and credits for actors, producer, director, writers and others. These titles often appear over an action background.

Enlargements: Portions of an original scene which have been enlarged to full-screen proportions.

Zooms: The camera appears to be airborne as it approaches a certain portion of the original scene.

Skip Frame: The original action is speeded up by omitting frames at regular intervals.

Hold Frame: A single frame of the original action is held for a given interval of time, so that the action is "frozen" on the screen.

Retarded Action: The action is retarded by repeating certain frames of the original scene.

Reverse Action: Forward motion is converted to backward motion.

Reverse Direction: The aspect of the picture is reversed, left to right. Sometimes called a "flop-over."

Montage: Many scenes appear in a potpourri of images, either successively, simultaneously, or both.

Anamorphosing: Scenes photographed with normal lenses are compressed laterally so that they are suitable for projection with CinemaScope-type lenses.

De-anamorphosing: Scenes photographed with CinemaScope-type lenses are expanded laterally to permit projection with normal lenses.

All of these special effects have one thing in common. The end result of incorporating each, mechanically speaking, is a *duplicate negative.* Therefore the goal of the cine technician who is charged with the making of any of these effects is the production of a *good,* dupe negative. The basic photographic technique for making a dupe negative remains the same, no matter what type of effect is being created. The difference between one type of effect and another is thus a question of manipulating the various components of film and equipment so that the desired visual rendition is achieved.

In black-and-white work a dupe negative is made from a fine-grain master printed from the camera original negative. The photographic contrast of the fine-grain master is selected to allow the dupe negative to be developed to attain the same contrast exhibited by the original negative. In preparing any of the special effects which we have enumerated, one or more fine-grain master positives are printed successively onto the duplicate negative film in a manner that will yield the desired composite photographic image.

The printer on which this is done may be either of the contact type or, preferably, of the optical type. A basic requirement of this printer is that it be equipped with a shutter that can be gradually opened and closed, either manually or automatically. In a contact printer only the simpler types of effects are possible, such as dissolves and fades. An optical printer must be used wherever there is to be a change in size or position of the images as copied from the fine-grain master onto the duplicate negative film. There is no inherent difference in quality, however, between dupe negatives made in a contact printer and those made in an optical printer.

In considering the making of special effects using integral multilayer negative-positive color films, we must first recognize that the basic process of making the color dupe negative is far more complicated than in black-and-white work. As we have seen, one of two procedures may be used. In the first procedure, three separation master positives are produced by printing the color camera original negative onto three fine-grain panchromatic black-and-white films through a red, a green and a blue filter, successively. Each of these separation masters constitutes, therefore, a silver-image record of one of the primary color components contained in the original color negative. These separation masters are then printed one after another and in register, through the appropriate red, green or blue filter, onto the color duplicating negative material to reconstitute a color negative into which the desired special effect has been incorporated.

Let us examine the procedure for making a simple lap dissolve in color by this technique:

1: First, three color-separation master positives are printed from the color camera original negative — one through a red filter, one through a green filter and one through a blue filter. These separation masters are then developed, to produce three black-and-white positives of *the first scene* of the lap dissolve (the scene to be dissolved from).

2: Three color-separation masters are likewise printed and developed to produce three black-and-white positives of *the second scene* of the lap dissolve (the scene to be dissolved to).

3: The separation positives of the red, green and blue components of the *first* scene are exposed successively onto the color dupe negative film, manipulating the shutter on the printer during each printing so that this first scene will gradually grow lighter on the processed color dupe until only clear film remains. This will cause the first scene of the dissolve to fade out in the color viewing print which will be made from the color dupe.

4: The separation positives of the red, green and blue components of the second scene are exposed successively onto the color dupe negative film, manipulating the shutter on the printer during each printing so that this second scene will start with clear film (no exposure) on the dupe and gradually appear. This will cause the second scene of the dissolve to fade in on the color viewing print. Because the fade-out portion of the first scene has been "double-exposed" on the dupe negative over the fade-in portion of the second scene, the result is that the first scene disappears on the color viewing print while the second scene simultaneously appears.

5: The color dupe negative, having been exposed, is now developed in a color negative processing machine.

It can be seen then, that the procedure for one simple lap dissolve involves two scenes of original negative, six separation master positives, six controlled exposures in register onto the color duplicating negative film, plus the processing of the masters and the dupe. More complicated special effects such as stationary and traveling mattes are merely variations of this same technique, differing only in complexity from the operations just described.

In the second procedure, a multilayer color material is used to prepare both the color master positive and the color duplicate negative. The number of operations is therefore considerably reduced, resulting in a large saving in time.

The final responsibility for the selection and placement of a special effect in a motion picture belongs to the film editor. The specification for a special effect is largely numerical in expression, and designated as "the counts."

Some film processing laboratories have adapted the "A and B" technique of obtaining lap dissolves and fades with the multilayer color negative-positive process. This technique, which has been used for many years in printing 16mm color reversal films, produces excellent lap dissolves and fades without recourse to separation masters or dupe negatives. It is especially useful, therefore, for introducing dissolves and fades into a "preview" print before any release prints have been made.

In this technique each reel of camera original negative is assembled in the form of two rolls, the "A" roll and the "B" roll. In assembling these rolls certain scenes will be placed in the A roll, and other scenes will be placed in the B roll. Whenever any scene is in the A roll its exact length is duplicated in the B roll by clear film or opaque leader.

If a lap dissolve is desired in the finished print between Scene One and Scene Two, for example, Scene One will be placed in the A roll. Scene Two will be placed in the B roll, following a length of opaque film just long enough that, if the A and B rolls were laid out one on top of the other, the two scenes would overlap in the region where the dissolve is planned.

The color positive raw stock is printed first from the A roll, rewound, then printed from the B roll. Scene One prints from the A roll; but where Scene Two will print from the B roll there is opaque film in the A roll, and nothing prints from the A roll in this area except in the overlap region, where the dissolve will occur. Likewise, because of the opaque film in the B roll, nothing prints from the B roll where Scene One prints from the A roll, except in the overlap region. If there were no dissolve shutter on the printing machine the result after printing both the A and the B rolls would be as follows: Scene One, followed by the overlap region where both Scene One and Scene Two have printed, followed by Scene Two.

There is a dissolve shutter, however, which is activated automatically at the proper point of the overlap during the printing of the A roll. This causes Scene One to fade out in the overlap area. Similarly, the shutter is activated automatically in the opposite direction when the B roll of negative is printed. Thus Scene Two is caused to fade in while Scene One is fading out, thereby giving us a dissolve between the two scenes. This is shown schematically in Fig. 26.

Fade-outs and fade-ins are made by overlapping a scene in one roll with a section of clear film in the other. This causes the dissolve shutter to fade out Scene One completely before it begins to fade in Scene Two.

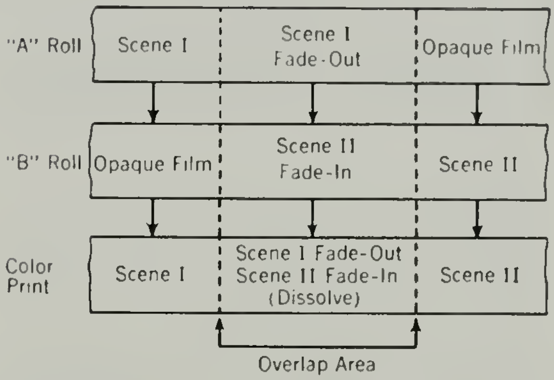


FIGURE 26: A lap dissolve by "A and B" method.

(Courtesy Consolidated Film Industries.)

10. Color Processing and Printing

Generally speaking, laboratory procedures involved in handling color film are basically the same as for black-and-white, as is evidenced by the fact that most black-and-white laboratories have successfully entered the color field. The same laboratory technicians work in both media with little change in classification. However, color has brought important new concepts to the motion-picture laboratory, as well as to other phases of the industry.

As we have seen, there are two fundamental processes currently used for the production of motion pictures in color — the multilayer color negative-positive process (Anscocolor, Eastmancolor), and the imbibition process (Technicolor). Both of these are subtractive processes — that is, they control the red, green and blue content of the light reaching a viewer's eye by subtracting these additive primary colors in varying amounts from a single white-light source (the projector lamp) by means of cyan, magenta and yellow dyes in the film. The color TV industry is experimenting with at least two other processes — both additive processes — which we shall consider briefly later on. Additive systems have been tried by the motion-picture industry without commercial success. This is not because of the color quality which can be obtained, but primarily because of technical difficulties involved. These difficulties might not be insurmountable, practically, for some television applications, as we shall see.

TECHNICOLOR IMBIBITION PROCESS

We have considered the Technicolor Process in some detail in connection with our discussion of films and processes. Let us review it briefly here.

Original photography may be done either on "three-strip" negative or on a one-strip multilayer color negative film. If on three-strip negative, a Technicolor matrix is made from each of the red, green and blue negatives exposed simultaneously in the Technicolor Three-Strip Camera. If the original exposure is made on a multilayer color negative film, three separation matrices are made from the color negative through red, green and blue filters. In either case, the final imbibition print is made by transferring successively, cyan, magenta and yellow dyes from the red, green and blue matrices to a single imbibition print film. Since the dye images are transferred from three matrices, one after another, to a single print film, they must be transferred in exact superposition, or "register," if the print is to appear sharp and clear.

MULTILAYER COLOR PROCESSES

Reviewing now the use of multilayer color processes, we have seen that original photography was done on multilayer color negative film. From this color negative a color positive print can be made directly, except for those scenes which will require dissolves, fades or other special effects. On these scenes, one of two procedures may be followed. In the first, three black-and-white separation positives are prepared from the color negative original. These separation positives are then used to prepare a color internegative in which are incorporated the special effects. In the second procedure, a color master positive is prepared from the color negative original and the former is then used to prepare a color duplicate negative which incorporates the effects. The color dupe scenes are then cut into the original negative and the color release prints are made by continuous contact printing onto multilayer color positive film.

MULTILAYER COLOR FILM PROCESSING

Before turning to the details of color film processing, let us review what happens when a black-and-white film is developed, or processed. The emulsion of a black-and-white film consists of two components — silver halide grains and a binder. The silver halide grains (silver chloride, bromide or iodide) are the part of the film which make it sensitive to light. The binder, usually gelatin, serves to hold the grains in place physically, yet allows the processing solutions to reach them. The exposure — that is, light falling on the film — causes a slight invisible physical change in the silver halide grains of the emulsion. This is known as a latent image. This slight change can be greatly enhanced by the chemical energy of the developing solution, so that a visible image of pure metallic silver results after development. This silver image can be produced by the developer only where light has first caused a slight physical change, or latent image. Any silver halide grain which has not been exposed will not be reduced to a metallic silver image when the film is passed through the developing solution.

Since during exposure not all the silver halide grains were affected by light (if they were, we would have nothing but uniformly black frames), we must now remove the silver halide that was not exposed. These are still sensitive to light and would interfere with our ability to print the film unless removed. This we do by passing the film into a "fixing" solution. The latter consists primarily of a solution of sodium thiosulfate, more familiarly known as "hypo." The fixing solution dissolves away all the silver halide remaining in the film, but does not affect the developed silver image.

Now let us see what takes place when a multilayer color negative or positive film is developed. As we know, there are three superimposed emulsion layers on a single support, one which responds to blue light, one to green light and one to red light. There is a further fundamental difference between black-and-white and such color films — each emulsion layer contains a third ingredient called a "color former," in addition to the silver halide grains and gelatin. This "color former" is a chemical which reacts with certain special color developing agents (developers used for black-and-white films will not work) to form a colored dye *in the immediate vicinity of a silver halide grain being developed to silver.* There is a different color former in each layer, so that three different dye colors are formed.

The first step of color processing is development. As with black-and-white films the chemical action of the developer produces a silver image from those grains in which a latent image had been formed by exposure to light. Since each of the three emulsions responds to only one of the primary colors, we have in effect three black-and-white separation negatives, one below the other, on a single film support.

Because of the presence of color formers, however, our images in the multilayer color film are composed of both silver and dye. A cyan dye is formed by the developer along with the silver image in one layer, magenta in another, and yellow in the third. The amount of the dye formed is proportional to the amount of silver in the image, since the chemical reaction that converts the color former to a colored dye is dependent on the reaction which converts exposed silver halide to silver. Thus, where a large amount of exposing light strikes a layer, a large amount of silver is formed and a large amount of dye is formed with the silver. Conversely a small amount of exposure produces a small amount of silver and a small amount of dye.

Just as in the case of black-and-white film, the unexposed silver halide grains which were not used in forming the picture image must be dissolved out by immersing the film in the "fixing" solution. The processing steps up through this point must be carried out in complete or almost complete darkness. Subsequent steps may be done in white light, for the film is no longer light-sensitive after fixation.

We now have a silver and a dye image in each layer. Only the dye image is desired, so we must eliminate the silver. We do this by passing the film into a "bleach" solution. The active ingredient of the bleach, most commonly potassium ferricyanide or sodium dichromate, reacts with the silver to form a silver compound which, though not readily soluble in plain water, is easily dissolved out of the film by a sodium thiosulfate solution. Thus the next step in processing is to pass the film into a second "fixer." The dye image is not affected by either the bleach or fixer solutions. After this operation the film is washed to remove all residual chemicals, then dried. This processing cycle results in a film which has a cyan image in one layer, a magenta image in another, and a yellow image in another. There are some differences in solution make-up and techniques between films of different manufactures, and between positive and negative films of the same manufacturer, but basically the processing procedures for all multilayer color films are as we have described. They are sufficiently similar to black-and-white procedures that color films may be processed in black-and-white developing machines, providing tanks for the extra solutions (bleach and extra "fixer") are added.

LABORATORY FILM FLOW

Let us follow the flow of a picture photographed on multilayer color negative through the laboratory. Immediately after the color negative is exposed, it should be processed on the color negative processing machine. Color negative, being a more complex film than black-and-white, cannot be stored for long between exposing and processing unless kept at a temperature well below freezing. Otherwise the physical effect of the exposing light (latent image) decays rapidly. It also tends to decay at different rates in the three emulsion layers, destroying the color balance of the film.

Negative processing is done as soon as possible after the film reaches the laboratory. A day's shooting usually comes into the laboratory sometime before midnight of the same day (except film from a distant location, in which case shipping time must be considered). The processing is completed by early morning, and the film sent to the negative assembly room. Here the "out-takes" — shots which have been photographed more than once and are not to be printed — are removed and the negative is spliced for the printing of "dailies." The negative is then cleaned and sent to the printing room.

Depending on the customer's choice, there are several ways in which the dailies may be printed. They may be in color or in black-and-white, they may be uncorrected (reasonably good color reproduction, but not compensated for normal variations in printer adjustment, negative exposure, etc.) or fully color corrected. In the interest of economy, many of the "dailies" are printed in black-and-white. Large productions, however, where economy and speed of delivery are not factors, usually require fully color-corrected "dailies." After printing, the "dailies" are processed on the color positive developing machine and sent to the customer. Approximately 24 hours elapse from the time the exposed negative is received by the laboratory until the "dailies" are shipped. After daily printing, the negative is stored in film vaults until it is needed for special effects and release printing.

The next laboratory step is preparing the production for release printing. This requires integrating the editing, special-effects photography and laboratory work. The film editor uses the "dailies" as a work print and sometimes as a preview print, in the same manner as for black-and-white film. When the edited picture reaches the laboratory it is handled much like black-and-white, except where duplicate negatives are required. Here two problems are introduced — registration and contrast balance. We have mentioned photographic contrast, or "gamma" as it is sometimes called, in connection with other topics. Let us pause here to consider it just a bit more in detail.

When we photograph a scene containing a variety of objects ranging from dark to light, we want to have in the photographic reproduction a brightness relationship among these various objects which *appears* to duplicate that of the original scene. We can change this brightness relationship among the various objects of a scene, either by intent or by lack of complete control of a color process, so that the photographic contrast is either greater or less than normal. If greater, the gamma is said to be high; if less, the gamma is said to be low. If a higher than normal gamma is introduced into the photographic process without compensation, the final reproduction will appear "hard," with no subtle gradations between light and dark areas. Light colors wash out to white, and dark colors degenerate to near-blacks. Detail is lost in all but the middle tones. Likewise, a lower than normal gamma will result in a "soft," muddy reproduction in which white and pastel colors reproduce too dark, whereas black and dark colors reproduce too light.

If the gamma of one emulsion layer is too high or too low with respect to the others, very peculiar colors and color changes are produced, as we have seen. This problem of contrast balance presents a subtle difficulty in making fades and dissolves, because objects in a scene become darker and darker as the fade progresses. Lack of contrast balance means that these objects will change color during the fade or dissolve — a very peculiar and disturbing effect.

Careful exposure and processing of multilayer color films will retain the normal photographic contrast built into each emulsion layer by the manufacturer. When separation master positives and color dupe negatives are made, however, the sharpness, the contrast and the color quality of the final reproduction may be significantly affected by the laboratory. The color separation masters must be exposed, processed and printed back to the color duplicating negative in such a way that the three primary color records do not become unbalanced. They must also be kept in very precise registration or a lack of sharpness, which of itself will introduce one kind of color degradation, will result.

These three records must register with each other so that the same objects in each corresponding frame superpose within a tolerable error of about 500 millionths of an inch (critical observers can detect as little as 200 millionths of an inch mis-register in a sharp color print). Precision like this requires well-designed equipment and a high degree of operating skill, but it is standard practice for color master positives and dupe negatives.

After the editing is completed and all the effects are made, the laboratory then proceeds to make the "answer" print. This is a print which is expected to be in all respects — color balance, story quality, effects, pace, etc. — exactly what the producer and his associates expect their picture to be. Hence the name, "answer print." Of course, hardly any first answer print succeeds in this respect. There are always minor changes of one kind or another to be made, and two, three, four or more answer prints may be required. But eventually a print is produced which is exactly what the producer wants. The order is then given to the laboratory to make the release prints exactly like this one.

Release prints are then made according to the specifications represented by the answer print. Each reel is inspected to make sure that it is, within commercial limits, a reasonably good replica of the final answer print in all respects. This procedure as regards answer prints and release prints is the same, of course, whether a multilayer color process or the Technicolor imbibition process is employed.

PRINTING AND PROCESSING EQUIPMENT FOR MULTILAYER COLOR FILM

As we said earlier, black-and-white printing and processing equipment, suitably modified, can be used for multilayer color film; however, a much better job can be done with equipment designed specifically for color. Most of the laboratories that now print and process color began with black-and-white machines and built better equipment as they acquired experience.

Printing Machines

Color printing machines must have a means for moving film past an exposing aperture, a light source, and a means of controlling the intensity and color quality of the exposing light. This is essentially what is required for black-and-white, except that no provision for controlling the color quality of a black-and-white printer is required. Color printing requires about ten times the amount of light required for black-and-white, so a bigger lamp and a more efficient optical system are required. Printing machines designed specifically for color have aimed mainly at improving the light output, and getting a good, reliable method of controlling color balance.

In 1951 and 1952 color control was obtained subtractively, by inserting a "pack" of cyan, magenta and yellow filters into the optical path of a printer. This was not ideal, because the dyes faded rapidly in the intense light beam. Later color printers are of the additive type, that is, the printer has three beams of light (red, green and blue) instead of a single beam of white light. These three beams are independently controlled by neutral density filters or by other means, and are "added" together to form white light of the proper color balance just before they reach the film. This system gives better color quality and uses light very efficiently. The neutral density filters can be made very stable. Thus the light output is high and the maintenance low.

Color processing machines must provide a means of continuously moving film through fresh processing solutions, a means of drying the film, a means of controlling temperature of the various solutions, and, on a machine for processing color positive film, a means of applying a sound record (soundtrack). Again, these are basically the same requirements as for black-and-white processing machines except that temperature control is more critical, and the sound-record application is additional. Temperature should be controlled to within at least one-half degree Fahrenheit, but this is not too difficult with commercially available temperature control systems.

The sound record presents a problem because of the fact that the color image is composed of dyes rather than silver. The standard sound system in the average theater will not respond properly to a dye sound record because of the characteristics of the phototube employed in the sound reproducer. Attempts have been made to convert the theater sound systems to operate with a dye track by changing to a suitable phototube, but without success. This may seem incongruous in view of the extensive changes in theater sound and projection equipment which have been introduced by the large-screen and stereophonic techniques. Yet the resistance to this change has been firm, partly because Technicolor imbibition prints carry a silver sound record and have no need for such a change. The motion-picture industry had to devise a way, therefore, to produce a silver sound record on multilayer color film. This is done as follows:

After development of the color positive in the color developer, the sound-record area as well as the picture area contains both a silver and a dye image, plus unused silver halide. The first fixing bath which follows removes the unused silver halide. The next solution, the bleach, is of a special type, known as a re-halogenizing bleach. This solution re-converts the silver image in both the picture and the sound-record areas to silver halide. It is then possible to *redevelop the sound-record area only* by means of a "fogging" developer. This developer is applied by means of an applicator wheel, and a thickening agent has been included in the developer to give it a syrup-like consistency, thus permitting it to be applied without spreading. This treatment results in a sound record containing both a silver and a dye (previously formed) image. After a brief wash, the film enters a second fixing bath which removes the unwanted silver halide still remaining in the picture area. Final washing completes the process.

Another scheme, which has been used extensively in Europe, is to apply a paste-type bleach to the *picture area only*. This removes the silver from the picture image, leaving only the dye image in the picture area. The sound record is untouched, and contains both a silver and a dye image. Now the entire film is fixed and washed.

TIMING AND COLOR CORRECTION

In order that the color print made from a color negative be an acceptable reproduction of the original scene, the print must be exposed with light of precisely the right intensity and the right color quality, as we have seen. Normally a laboratory maintains tight control over printing and processing variables, but there is one important variable over which it has no control at all; namely, the exposure of the original negative. And since with all multilayer color negative films any significant deviation from a normal exposure will necessitate both density and color corrections in the print, the laboratory is constantly faced with the problem of compensating for any under- or over-exposure of the negative.

This does not imply any lack of skill or judgment on the part of the cinematographer, who very often has to compromise his exposure for reasons of depth of focus, insufficient light, or the necessity of obtaining a special photographic effect. It does mean, however, that the laboratory must be prepared to compensate for any deviation from a normal negative exposure, no matter what the reason, in order to color-correct the print.

Color timing is also essential because of differences in the type of scene. Even for correctly exposed negatives, certain types of scenes will require a different printer color balance than others in order to give the best reproduction. This will be governed by whether one is trying to obtain good flesh tone reproduction, good reproduction of a landscape, or other criteria. Color timing is also essential because of the adaptation effects resulting when viewing the final print. For example, if one scene carries a predominant color it will affect an observer's judgment of the subsequent scene. Accordingly, the printer color balance must be modified to compensate for these effects. We will discuss this in more detail under "Visual Effects."

A survey of a large number of color motion-picture negatives exposed and processed under standard conditions will lead to the selection of a so-called average or normal negative. The intensity and color quality of the printing light most desirable for printing this normal negative would be considered the normal printing light. It follows then that any negatives which differ from the average or normal negative will require alterations in printing light color and intensity. This requirement leads to two basic problems:

(1) How to select the proper intensity and color quality of the printing light.

(2) How to change the intensity and color quality of the printing light for each scene as it is printed.

The solution to the first problem is known as "timing" the print. It is carried out with the help of a machine known as a "light tester," and by experienced technicians, known as "timers," who can evaluate a print and prescribe the proper printing light variations for each scene in order to produce a color corrected print. The solution to the second problem is an adjunct to the printing machine called a "light changer" or "light modulator." It is usually actuated by notches punched along the edge of the negative farther from the sound record. These notches cause the light changer to vary the intensity and color balance of the printing light a predetermined amount for each scene.

Variation in negative exposure is not the only factor which must be compensated for in timing and color correcting a print. Variations in speed and color balance of both negative and positive films, either in manufacturing or in storage, and latent-image decay of a color negative film after exposure are also factors which may require color compensation in the laboratory.

11. Motion Pictures and Color Television

TELEVISION PROGRAMS ON FILM

Contrast Limitations of Television

As we noted earlier, the contrast range of the television system is severely limited as compared to that of a color motion picture on a theater screen. The color film can reproduce a contrast range of about 100 to 1, whereas a color television picture on a home receiver is limited to about 20 to 1. Color film produced for television use must be made with this limitation firmly in mind, or the quality of the reproduction we finally see on the color TV receiver is a far cry, indeed, from the quality which the color television system is capable of reproducing. It is for this reason that the subject lighting contrast must be kept lower for color motion pictures made for TV than for those made for theatrical presentation. Unless this is done, a severe tonal compression results, which eliminates shadow detail in the televised reproduction and seriously degrades picture quality. Ideally, lighting ratios of 1½ to 1, or 2 to 1 at most, should be maintained unless special lighting effects are desired.

Sharpness Limitations

The color television system, presenting a smaller picture and possessing considerably lower resolution capabilities than the theater screen, requires that long shots, busy backgrounds and small detail be used sparingly. Close-ups are emphasized and "tightened" in films for TV use, in order to obtain sufficiently fine detail. Illumination levels must be kept high enough to allow stopping down the camera lens for adequate depth of field.

Color Limitations

The color television system is an additive system, not a subtractive system as in the case of the color films previously discussed. Thus, instead of generating color by means of dyes which subtract varying amounts of red, green and blue from the white light, it generates red, green and blue light by means of phosphors on the face of the color picture tube, combining these primary colors in the proper amounts to reproduce a scene. The green and blue phosphors are quite good for color quality. The red phosphor, however, is far from ideal; it emits red light which is too orange in hue, and lacking in saturation. This makes for weak reds, and distortion of hue and saturation of colors containing reds. Also, the light sources used for projecting motion-picture film for television transmission, known as film "scanners," use phosphors which suffer from similar deficiencies.

We are not trying to say here that color television is bad color, or that color film is good color. As we have already noted, color distortions are inherent in all color films and processes. But the distortions inherent in color television and those inherent in color film are different, and affect the final color reproduction of a scene in a different manner.

Color television is limited in brightness, and can reproduce saturated colors only at relatively high brightness levels. Conversely, color film has a much greater brightness range, but can reproduce saturated colors only at low brightness levels. Thus color film and color television are in a sense incompatible, for their color gamuts only partially overlap. This situation can be improved greatly by an electronic masking technique. Nevertheless, as we saw earlier, if a color film is properly planned and photographed for television presentation, a much better reproduction will be brought to the TV screen.

High-key lighting results in the most consistently pure color reproduction. Low-key lighting is far less predictable for color, and tends to give a muddy reproduction. Uniformity of lighting in the "playing area" of a screen is essential for television, for small variations in illumination can result in exaggerated deviations in the fidelity of color reproduction. Colored lighting effects must be used carefully, as they often make a black-and-white TV picture from the color film very confusing.

KINESCOPE RECORDING

Motion-picture film is used by the television industry not only as a source of original program material, but also as a means of recording television programs for later transmission.

In the first instance, live action has been photographed and reproduced on film for television transmission, just as it is photographed and reproduced on film for theatrical presentation. In the second instance, film is used to photograph a television reproduction of live action by photographing the images on the "face" of a TV picture tube. This yields a photographic copy which can be used for later TV broadcasts. Such photographic copies are known by various names such as kinescope recordings, television transcriptions, telecine recordings, etc.

The use of kinescope recordings has had a tremendous impact on black-and-white television programming. It has enabled small, non-interconnected stations to transmit big network programs at time periods most suitable to their own operation; and it has permitted sponsors and agencies to enjoy a certain amount of freedom in scheduling their shows throughout various sections of the country, as required by time-zone differences or the needs of regional advertising campaigns.

Kinescope recordings are also vital to the operation of network programs which must be broadcast at a specific time in each time zone. Let us suppose that a program must be "on the air" at 7:00 P.M. across the country, and that the program originates in Hollywood. It is broadcast live at 4:00 P.M. Pacific time for New York reception at 7:00 P.M. Eastern time. It will have to be kinescope recorded in Chicago (6:00 P.M. Central time) for transmission 1 hour later; in Denver (5:00 P.M. Mountain time) for transmission 2 hours later, and in Los Angeles for rebroadcast 3 hours later. These and many other uses of kinescope recordings make them an integral part of any large television operation today, and it is conceivable that the value of color television recordings will be of even greater significance.

Color Kinescope Recordings on Color Film

One of the easiest ways to make a color kinescope recording is to photograph a color TV picture using a multilayer color film. The film can be either a color reversal film, which will produce a color positive kinescope recording, or a non-reversal color film, which will produce a color negative kinescope recording. Interestingly enough, it makes little difference to the television system whether it "sees" a negative or a positive image, for by the simple flick of a switch, TV can make a positive image out of a negative image electronically. Good, high-quality kinescope recordings of color television programs have been made on both 16mm and 35mm multilayer color motion-picture films. These recordings are then reproduced by means of color film scanners.

Color Kinescope Recordings on Black-and-White Film

We mentioned earlier that the television industry was experimenting with additive color processes for color reproduction. These processes are especially interesting for kinescope recording, not only because they use inexpensive black-and-white film which is quickly and simply processed, but also because additive processes are fundamentally more compatible with the color television system, which, as we have seen, is itself an additive color system.

Briefly, an additive motion-picture color process involves photographing through red, green and blue filters to produce three black-and-white separation positives. These positives can be obtained by photographing three strips of film simultaneously, as in the three-strip camera. Or, by means of a special optical device, a red, a green and a blue image may be reduced in size and fitted into the approximate area of a single 35mm frame. This latter system, of course, requires only one strip of film. In either case, separation positives may be made by exposing onto black-and-white reversal film which yields the separation positives directly, or by exposing onto black-and-white negative film and printing separation positives.

To reproduce the original color scene, these black-and-white positives are projected with red, green and blue light, and the light which passes through the three images is combined to yield an additive color reproduction. If the three-strip system is used, some means must be provided for registering the three strips exactly. With the single-strip system, the images are recombined by a special optical device similar to the one used during photography. The single-strip system requires a dimensionally stable film, and produces on 35mm film a picture which is less sharp than a 35mm three-strip system. The fundamental reason for the difference in sharpness lies in the fact that, since all three records are reduced in size to fit into the approximate area of a 35mm frame, we have in effect a 16mm rather than a 35mm print. But because the television picture is small compared to a theater picture, this difference in sharpness may not be significant.

Lenticular Film

A method of producing color motion pictures by means of a single strip of black-and-white film is the use of lenticular film.

Novel, but by no means new, lenticular film is a single black-and-white emulsion coated on a base which has been embossed on the non-emulsion side with a structure of tiny half-cylinder-shaped lenses or "lenticules." These are placed across the film and have a radius of curvature of about 1/500 of an inch. This structure of lenticules presents an appearance much like a washboard with each individual lenticule acting as a miniature cylindrical supplementary lens.

Lenticular film is exposed "backwards" — that is, through the base. The camera lens images a scene onto the lenticular structure of the base rather than directly onto the emulsion, as is usually the case. Each of the tiny lenticules then images through the base and onto the emulsion only that portion of the scene which has been imaged upon it. The entire picture, then, consists of a series of minute, juxtapositioned dots of varying density, just as in the case of a newspaper or a magazine illustration. Since the dots are too small to be resolved by the eye, they are not seen as individual dots, but rather as a smooth blend of densities.

To produce color with lenticular film, each of the minute lenticules must be caused to image a dot, one third of which represents each of the three primary colors. In other words, one third of each dot must represent red densities, one third must represent green densities and one third must represent blue densities. This is achieved by using a special filter before the camera lens, a filter which consists of three side-by-side bands, one band being red, one being green and one being blue.

If this film is projected through a similar filter the original scene can be reproduced in color. As was the case with the other single-strip additive system just described, there are technical problems associated with the lenticular system which have prevented its successful commercialization for theater use. As before, however, it is likely that these problems may be less severe for television, because the picture is smaller.

The foregoing discussion assumes that one photographs a color kinescope image and that a tricolor filter is used over the camera lens to separate the color information as it is recorded on the lenticular film. It is also possible to effect the separation by geometric means. In this instance, the red, green and blue aspects of the television signal are presented on three black-and-white monitor tubes. By means of a special optical system and appropriate masks, the three images are recorded in proper juxtaposition behind the lenticules without the aid of a tricolor filter. Thus, the entire operation can be carried out without the necessity of employing color phosphors or filters.

12. Visual Effects

In our discussion of color films and color processing we mentioned the deficiencies of the dyes available for use in subtractive systems of color photography. We shall now consider some of the other reasons why a color reproduction does not always turn out as we expect it to.

At first glance, it might seem that if we had a color process capable of yielding a point-for-point reproduction of a scene we could obtain a color reproduction equivalent to the original scene. Actually, even a physically perfect color process would fail in this respect, for it could not take into account the psychophysical factors of our visual mechanism. The response of a color process to an original scene must always be fixed; it cannot vary, as our visual response can vary. Furthermore, even a perfect color process cannot compensate for variations in the conditions under which the color reproduction might be viewed.

Let us consider further, then, the more important of the visual effects which influence our judgment of a given scene, together with the photographic consequences which they entail. We shall consider here only effects which are experienced by all observers, disregarding effects which vary with individuals. Emotional mood, stimulation of senses other than vision, personal associations of colors and objects with ideas, color blindness — these and other factors affect an individual's perception of color.

BRIGHTNESS ADAPTATION

As we have seen, one of the most remarkable characteristics of our visual mechanism is its ability to operate over a tremendous range of illumination levels. Dilation and contraction of the iris of the eye can account for a change in the light energy reaching the retina of only about 16 times at most. The process which allows great extension of this range by changes in the sensitivity of the retina is called *brightness adaptation.* The sensitivity of the retina increases in dim light and decreases in bright light in such a way that the effective response of the eye is maintained more or less constant. There are three main types of brightness adaptation — general, local and lateral — all constantly at work in the process of vision.

General Brightness Adaptation

General brightness adaptation — adaptation to the average brightness of a scene — is valuable in that it allows us to see well at almost any illumination level. From a photographic point of view, however, it has the disadvantage that we are unable, because of the variable sensitivity of our eyes, to estimate the actual intensity of the illumination. For example, when we enter a motion-picture stage from outdoors, the lower illumination level on the stage causes a gradual increase in sensitivity so that we eventually get the impression that the illumination indoors is just as intense as it was outdoors. Hence we are often surprised that we have to open the camera lens considerably more on a brightly lighted set than we do outdoors.

Some purely physical instrument such as a photoelectric exposure meter, however, is not misled in this respect. It sees illumination as the film sees it, and it tells us immediately that the lens must be opened up on the stage. Actually, the camera lens adjustments called for by the meter can be considered as a substitute for the power of general brightness adaptation which the film lacks.

In connection with exposure determinations, it is interesting to note that our judgment of the brightness of a scene is influenced to a considerable extent by the contrast of the lighting. For example, an outdoor scene on a gray overcast day appears less bright than a contrasty stage scene, yet the average brightness of the low-contrast, outdoor scene is usually much greater. Color effects also enter into such a comparison; our overestimation of the brightness of a stage scene is due in part to our tendency to associate high saturation of colors with bright sunlight conditions.

Local Brightness Adaptation

In the process of viewing any given scene, the eye views one object after another, stopping for a brief interval at each point of interest. At each of these stops a readjustment of brightness adaptation takes place locally. The readjustment is very rapid, but sometimes we are aware of after-images due to a lag in recovery of the local sensitivity of the retina. For example, if we look at a bright light, then shift our gaze to a bright-colored reflecting surface, we see a dark after-image of the light.

Lateral Brightness Adaptation

Sensitivity changes in local areas of the retina are often accompanied by similar changes in adjoining areas. This "sideways" or lateral brightness adaptation is exemplified by what happens when we look at a moderately dark object surrounded by considerably brighter ones. The sensitivity of the retina is decreased in the bright areas of the image formed on the retina, but at the same time the decrease in sensitivity extends into the dark areas of the image, thus producing an apparent darkening of the dark object. Such changes in the appearance of adjoining objects are known as *simultaneous brightness contrast effects.* They depend to a considerable degree on the relative areas and positions of the objects, and in extreme cases the amount of detail visible in a dark object may be decreased. The top two illustrations of Fig. 27 show the differences in the appearance of the same gray patch when it is seen against different backgrounds.

BRIGHTNESS CONSTANCY

Though we seldom stop to think about them, we are continually making mental adjustments in what we see. By making such adjustments we become aware of the true characteristics of an object, and are not misled by the purely physical aspects of the light reaching our eyes.

Various constancy phenomena are prominent among the mental adjustments we make. *Size constancy,* for example, is illustrated by the fact that people at a distance do not look smaller than those close at hand. A person at 100 yards is imaged on the retina only one-tenth the size he is at 10 yards, yet he does not look *smaller* — he simply looks *farther away. Approximate brightness constancy,* a similar effect, makes us tend to see objects in terms of their *reflecting power,* rather than the amount of light they actually reflect. Thus we can almost always identify a piece of white paper as white, even though it is placed in shadow where it actually reflects much less light to the eye than a piece of gray paper in full illumination. Psychophysically, brightness constancy is closely related to general and lateral brightness adaptation.

Although brightness constancy effects are very strong in viewing the original scene, they are usually much weaker in viewing a reproduction of the scene. This fact is extremely important to the cinematographer, for it means that to obtain the desired and planned effects indoors he must almost always make compensating adjustments in the lighting of the scene.

We remember that an outdoor scene illuminated by sunlight has the same amount of light falling on all the unshadowed areas. We saw that the illumination is the same over all sunlit parts of the scene area because the sun is such a tremendous distance away that its rays are all essentially parallel, making the distance of various objects from the light source negligible.

Indoors, however, the situation is entirely different; the light sources are relatively close to objects in the scene, so that their rays are not parallel, but diverging. This means that the distance between light source and object is vastly more important, for the illumination on an object decreases *proportionally by the square* as the distance between light source and object becomes greater. This means that if one object is twice as far from the light source as another object, it receives only *one-fourth* as much light; if an object is three times as far away it receives only *one-ninth* as much; etc.

This falling away of light on an indoor scene is a serious problem. Unless corrective measures are employed the fault will show up very strongly in the reproduction, even though brightness constancy makes it very difficult to see it at the time of photography. Brightness constancy tends to make all objects in a set appear normal to the eye, even though some of them may be illuminated at far too low a level for proper reproduction on film.

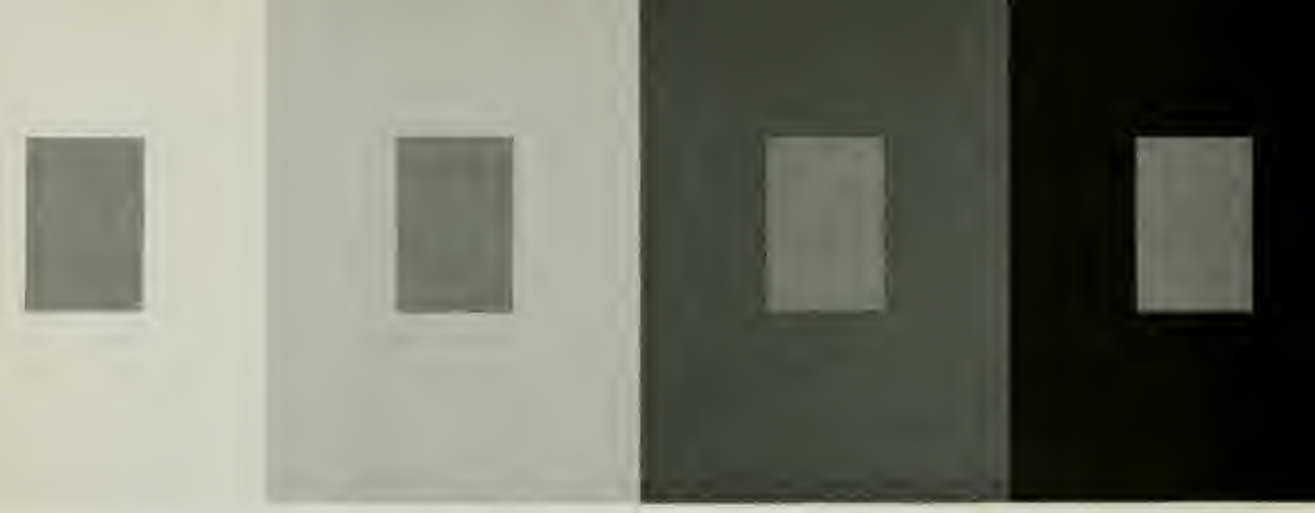
Background Rendering

Proper rendering of the background is very important in color, especially if our film is to be used for color television, as we have seen. When the subject is very near the background, say within two feet of it, separate illumination of the background is usually unnecessary.

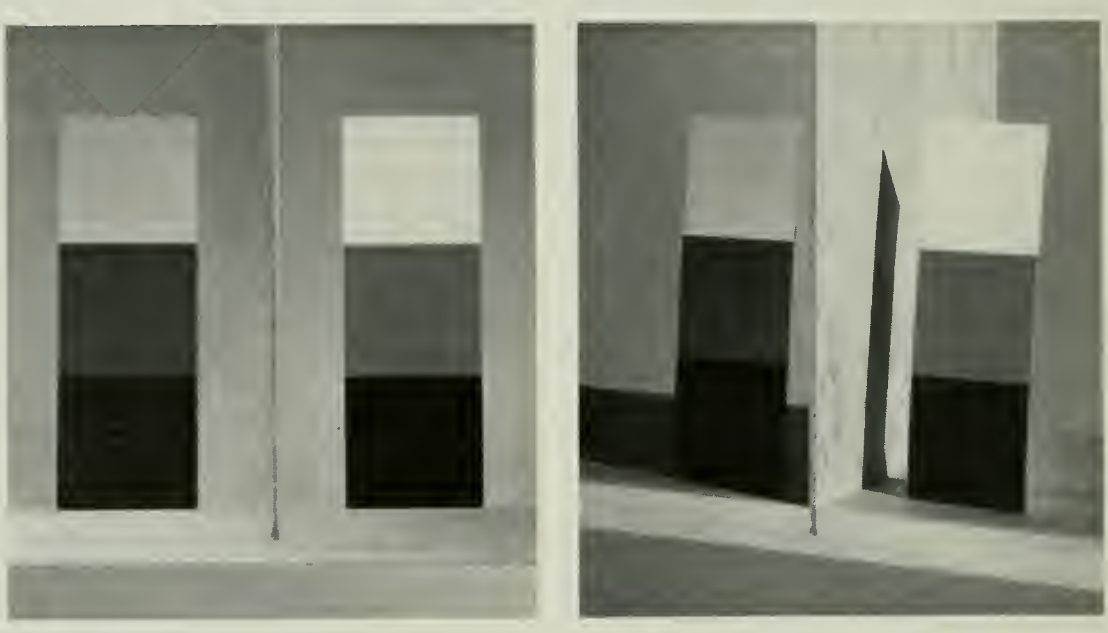
When the subject is farther away from the background, however, separate illumination is always employed because the illumination fall-off becomes serious, and the farther the background is from the principal subject the more it will tend to be seen as an unrelated object in the picture. The more unrelated a background appears — that is, the less it is connected to the principal subject by shadows falling on it — the weaker will be the brightness constancy effect carried over into the reproduction. Normal background rendering will be obtained only when the illumination falling on unshadowed areas of the background is approximately the same as that falling on the principal subject, as it is in sunlight.

Shadow Effects

The effects of brightness adaptation and brightness constancy are pronounced in large shadow areas of a scene. We may perceive these large shadow areas in three ways: first, as part of the scene as a whole (general brightness adaptation) : second, with the intent to see as much detail as possible within the shadow (local brightness adaptation) ; and third, we may look through it completely, so that the perception of a shadow, as such, tends to disappear (local brightness adaptation and the maximum brightness constancy effect) .



Although the central patch is exactly the same in all cases, simultaneous brightness contrast makes it appear to vary from dark to light as the background is changed from light to dark.



In the illustrations above, the two gray scales were exactly alike. In the illustration at the left, the lefthand gray scale looks darker than the righthand scale. At the right, the scene is shown from a different angle. Here, with the heavy shadow falling on the lefthand scale being evident as such, it is easier to believe that the two gray scales actually were alike. In viewing the original scene, brightness constancy made this fact obvious.

FIGURE 27: Effects due to brightness adaptation.
(Courtesy Eastman Kodak Company.)

These variations in the perception of shadows are not theoretical, but thoroughly practical, as can be seen from the illustrations of Fig. 28. When we see a familiar face we seldom notice the shadow of the nose, or whether the eyes are hidden in shadow. Instead, we picture that face mentally as if it were lighted in such a way that no shadows existed. Consequently we are surprised, and often we blame the limited latitude of film when we find the face half buried in deep shadow. *Brightness constancy has caused us to increase our sensitivity so as to see a scene which the film could not record under the circumstances.*

The strength of the brightness constancy effect carried over into photography — either color or black-and-white — depends strongly on the degree to which the non-uniformity of illumination falling on the original scene can be seen in the reproduction, as shown in the lower two illustrations of Fig. 27. However, in a two-dimensional reproduction of a scene there is always a serious loss of brightness constancy because the reproduction is viewed as an object in its own surroundings. *Hence the shadows always appear darker than they did in the original scene.* As a consequence, the most realistic results are obtained only when the lighting contrast of the scene *as viewed by the eye is very much less* in all respects than is desired in the final picture. This is the true basis for the term "flat lighting" which has so often been recommended for color photography.

Lighting Distribution

We have already seen that a background which is far enough behind the principal subject of a scene to appear unrelated to it, must be illuminated to approximately the same level as the subject if normal color rendering is to be obtained. Otherwise we may find, for example, that a poorly illuminated light-colored background appears darker in the picture than a strongly lighted dark-colored foreground object.

Actually, the same precaution applies to all parts of an indoor scene which are not visibly related to the principal subject in their lighting. Thus normal color rendering in all areas of the scene will be obtained *only when the whole scene is adequately illuminated.* If the lighting is not carefully distributed there may be areas that will be reproduced so dark that color and detail are lost. Such areas will be plainly visible on the film, even though brightness constancy makes them difficult to recognize in viewing the original scene at the time of photography.

COLOR ADAPTATION

Like brightness adaptation, color adaptation can be classified into three main types which operate simultaneously in the process of seeing. To a considerable extent, all three types of color adaptation function independently of the brightness adaptation effects.

General Color Adaptation

In viewing any given scene, the visual mechanism adapts its color sensitivity in such a way that the illumination tends to appear colorless (white). The power of adapting to the color quality of prevailing illumination is known as general color adaptation. By means of it we become less aware of the physical conditions associated with a scene at the time, and gain a better idea of how the scene would appear if viewed under conditions of our own choice. Thus we are not misled, for example, to the conclusion that a person seen at sunset is actually ruddy in hue.

If a scene is illuminated by two light sources which differ in color quality, the eye minimizes the color differences by adapting to an intermediate illumination color. Thus the effect of a scorched diffusion silk or a lamp of the wrong type is difficult to see in viewing the original scene, but is more noticeable in viewing the photographic reproduction.

Local Color Adaptation

When there are fairly intense colored areas in our field of view, sufficient exposure of our eyes to these colors affects subsequent vision in the corresponding areas of the retina. Fixation of the eye on a particular area for a brief time, followed by fixation on another surface, gives rise to characteristic colored afterimages. A familiar example of this effect can be seen in Fig. 29.

A very common effect of local color adaptation when viewing motion pictures is as follows: Let us suppose we have timed and color-corrected a certain scene until we feel that it is an excellent reproduction of the original scene. Let us now cut this scene into a reel so that it follows a scene of, say, a forest fire. Because of the very reddish overall color of the fire scene, the red sensitivity of our eyes is depressed, causing our perfectly timed scene which follows it to appear lacking in red — that is, cyanish. It is for this reason that the final timing of a motion-picture print must be done by eye rather than instrumentally, for the preceding scene often conditions our eyes so that a scene must be timed incorrectly in order to appear natural in its sequence in a reel. A scene which follows a forest fire, for example, must be timed too red in order to appear correctly timed. It *would* appear too red, however, if it were to be removed from the reel and viewed alone.

Lateral Color

The effect of colored areas on the appearance of an adjacent colored area is an enhancement of color contrast known as *simultaneous color contrast.* The group of four illustrations at the bottom of Fig. 4 demonstrates both brightness contrast and color contrast effects. The bluer appearance of the central patch at the lower left is due to simultaneous color contrast.

COLOR CONSTANCY

Perhaps the most important of all the effects due to visual adaptation is the phenomenon known as *approximate color constancy.* As we saw earlier, even though the character of the radiant energy reflected from a colored object varies considerably, depending upon the color quality of the illumination, we are not ordinarily aware that there is much difference in the appearance of the object. In fact, we are accustomed to think of most colors as not changing at all. This effect is due largely to our tendency to remember colors rather than to look at them closely.

We do *fear* at times that the color of an article may look different in daylight than it appears under tungsten light. For example, in buying a suit we may take it to a window. There we form a mental picture of the suit in daylight, and this appearance becomes the "real" color of the suit, even if we later see it under a wide variety of illumination conditions. Our tendency to accept the daylight color of an object as our mental standard is undoubtedly based on the fact that man has always depended on the sun as his most important source of illumination.

Although the color constancy effect is strong for most colors and most light sources, under certain conditions the color of an object may change decidedly. Look again at the top two illustrations of Fig. 4.

MODES OF APPEARANCE

Another condition which affects our perception of a color is known as its *mode of appearance.* We can classify the various modes according to the attributes which characterize them. For example, color seen in the *illumination mode* has hue, brightness and saturation, but no size or shape; it results merely from the awareness of the distribution of radiant energy in space. On the other hand, a glowing object, seen in the *illuminant mode,* has additional attributes such as size, shape and location.

Colored objects are seen in the *surface mode* or the *volume mode.* In either case they have size, shape and location, but only objects perceived in the surface mode can have such attributes as glossiness and luster. A volume color, such as haze or smoke, cannot have these attributes. Furthermore, volume colors must always be at least somewhat transparent, while surface colors may be completely opaque. (Note that the term "surface color" is used in a different sense here than in describing the characteristic surface reflections of metals.)

When a color appears to have neither the characteristics of surface nor those of volume, as for example, a blue sky seen through the exit of a darkened tunnel, it is seen in the *aperture mode.* A color seen in this way is called an *unrelated color,* because it is judged without comparison to other colors or to the surroundings. Such colors never appear to contain gray or black, for we do not have the brighter surroundings with which we normally compare them. Thus in an isolated field we can never see "grayed-down" colors such as brown, olive-drab and navy blue; instead we see orange-red, greenish-yellow and blue respectively. The amount of gray seen in colors under different viewing conditions is of fundamental importance to the apparent quality of photographic color reproductions.

VIEWING COLOR PICTURES

The most favorable condition under which a color motion picture can be viewed is by projection in an otherwise completely dark room. The screen then becomes an isolated patch of colors with a completely dark surrounding. Under these conditions the eye adapts in such a way that a maximum amount of the gray added by the unwanted absorption of the dyes is removed from all the colors; it also adapts, over a very wide range, to the overall color balance of the picture. Both of these effects make the reproduction appear *more nearly correct than it really is.*

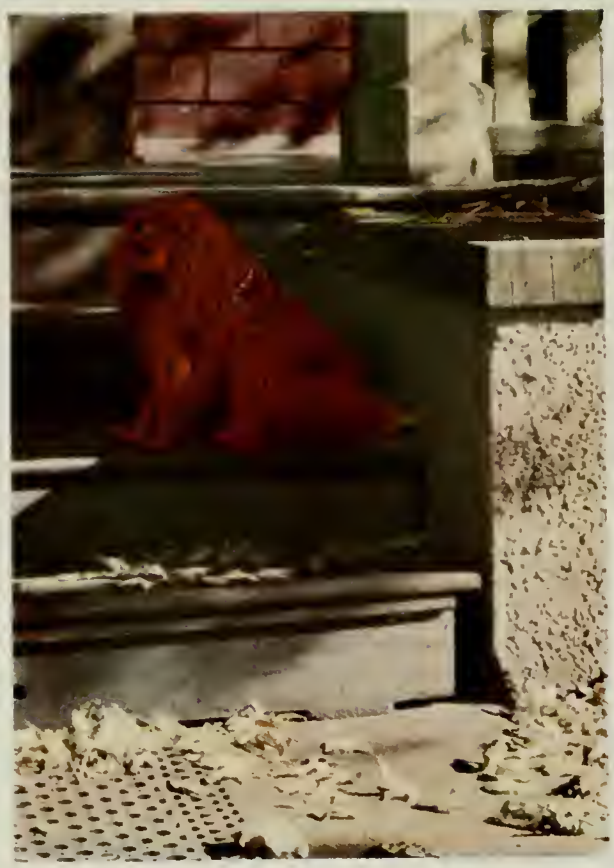
If a motion picture is viewed in a partially darkened room, the room illumination begins to compete with the screen illumination for the color and brightness adaptation of the eye. The brighter the room illumination, the more noticeable is the color of the projector light as such; then the better must be the color correction of the film, and the closer must the color of the room illumination match the color of the projector light if we are to maintain a picture of optimum color quality.

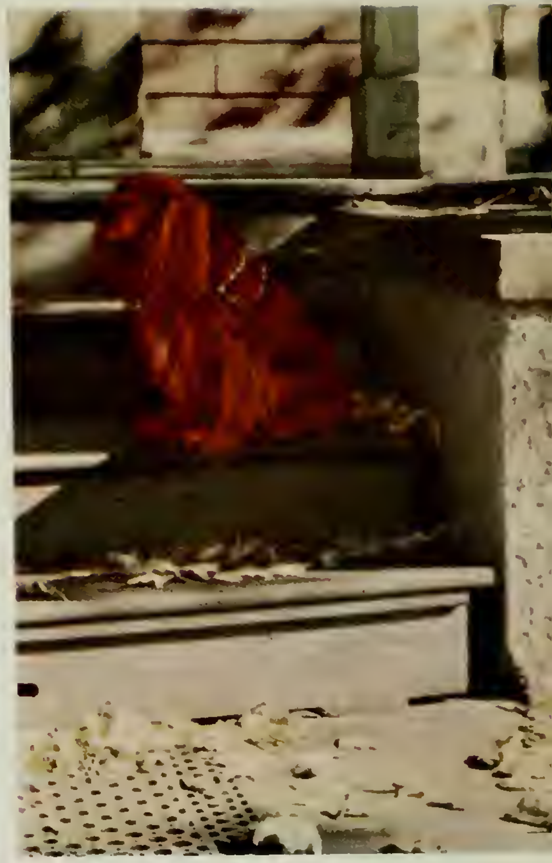
COLOR BLINDNESS

Few of us realize how large a proportion of the population has defective color vision — approximately 8 men in 100 and 4 women in 1000 are more or less color-blind. Of those displaying color-blindness, approximately 2 men in 100 and 3 women in 10,000 are afflicted in such a way that it is dangerous for them to engage in occupations requiring the proper recognition of colored signal lights. Fortunately, these serious cases can be identified with the test charts that most oculists have.

Color-blindness usually dates from birth, but may also be acquired as the result of certain types of injury, disease or poisoning. There are many types and degrees. Some individuals see one part of the spectrum as gray; others see another part as gray. Usually, however, people who are color-blind merely experience difficulty in distinguishing and naming colors. In many cases the deviation from normal color vision is so slight that it is never recognized.

There is no reason why the majority of people who are color-blind cannot engage in and enjoy color motion pictures. Those who are seriously afflicted should be cautious about undertaking occupations which require color discrimination, however, for they might produce results which are not acceptable to those having normal color vision.





(Upper left) In "looking at" a shadow, the shadow is seen as a dark area with little visible detail.

(Upper right) Focusing attention within the shadow, or "looking into" it, makes the shadow appear to become lighter, and detail within it is much more clearly seen.

(Right) Approaching the shadow and focusing attention even more strongly within it, or "looking through" it, makes the perception of a shadow as such tend to disappear.

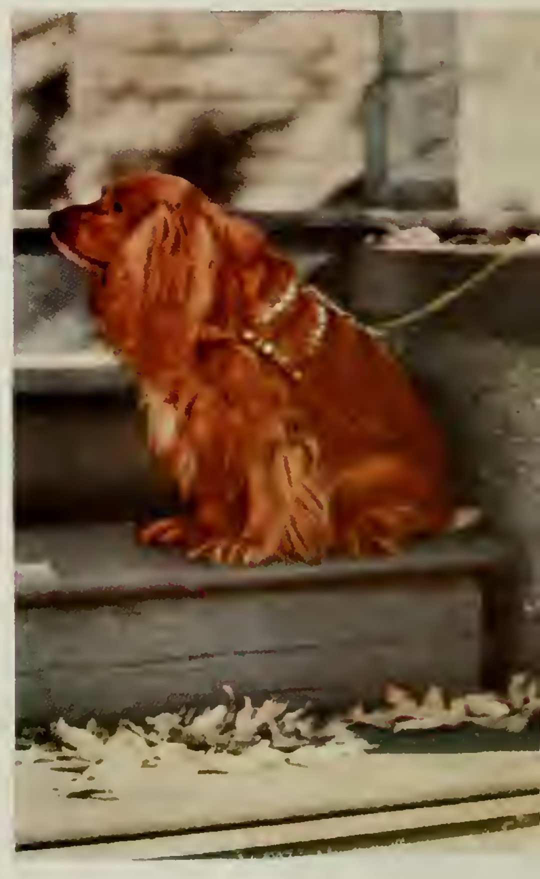
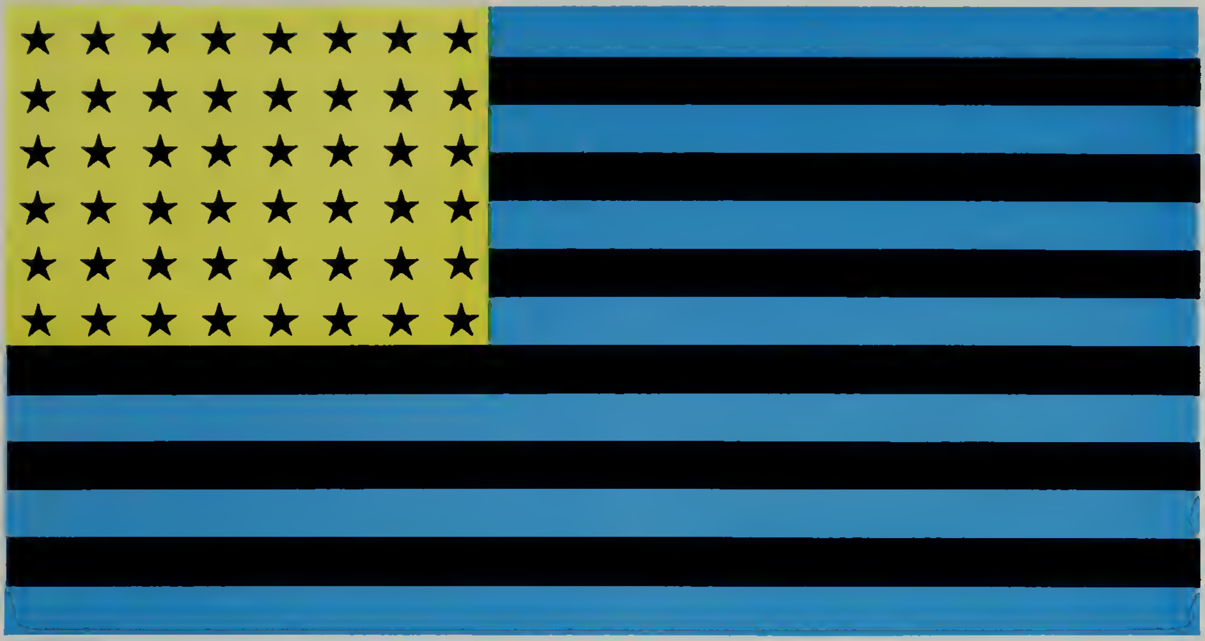


FIGURE 28

(Courtesy Eastman Kodak Company; reprinted with permission from Ralph M. Evans's *An Introduction to Color*, 1948, John Wiley & Sons, Inc.)



With this page illuminated by a fairly strong light, stare fixedly at the star in the lower right corner of the yellow field while counting 20 seconds. Then quickly shift your gaze to the black cross in the rectangle below. The flag will immediately appear in colors complementary to those printed above. The afterimage seen in this way is due to local color adaptation. In the area of the retina where the yellow field is at first imaged, for example, the sensitivities of the red and green receptar systems are reduced by prolonged exposure to a mixture of red and green light. Thus, when the yellow field is replaced by white paper, red and green are subtracted from the neutral white, and a blue image results. As the receptor systems recover their sensitivities, the afterimage fades.

FIGURE 29
(Courtesy Eastman Kodak Company.)

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Written by outstanding specialists of the motion-picture and television industr

A broad, basic,
yet thoroughly interesting
and understandable
treatment of professional
color motion pictures.